UNCLASSIFIED

AD NUMBER
AD398996
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to DoD only; Foreign Government Information; SEP 1968. Other requests shall be referred to Controlling Organization: British Embassy, 3100 Massachusetts Avenue, NW, Washinton, DC 20008.**
AUTHORITY
DSTL ltr dtd 15 Feb 2007

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD NUMBER	
AD398996	
CLASSIFICATION CHANGES	
TO:	**unclassified**
FROM:	**restricted**
LIMITATION CHANGES	
TO: **Distribution authorized to DoD only; Foreign Government Information; SEP 1968. Other requests shall be referred to Controlling Organization: British Embassy, 3100 Massachusetts Avenue, NW, Washinton, DC 20008.**	
FROM: **Distribution authorized to DoD only. Other requests shall be referred to .**	
AUTHORITY	
DSTL ltr dtd 15 Feb 2007 xxxx; DSTL ltr dtd 15 Feb 2007 xxxx	

THIS PAGE IS UNCLASSIFIED

JOURNAL

OF THE

ROYAL NAVAL SCIENTIFIC SERVICE

ROYAL NAVAL SCIENTIFIC SERVICE

Vol. 23 ★ SEPTEMBER 1968 ★ No. 5

RESTRICTED

Journal of the
ROYAL NAVAL SCIENTIFIC SERVICE

Decl OADR

VOL. 23, No. 5 SEPTEMBER, 1968

CONTENTS

[redacted]

EDITORIAL

September 3rd, 1968 saw the introduction of changes in the organisation of Headquarters departments responsible to Chief Scientist (Royal Navy). Members of the RNSS will no doubt be interested to know something of the reasons behind this and the way the new arrangements are intended to work.

It has been clear for some time that the previous organisation was not well matched to developments which have taken place in the last few years both in the Navy Department and in the Ministry of Defence as a whole. Changes of particular significance have been the appointment of Chief Scientist (Royal Navy) as a member of the Admiralty Board, the formation of the Naval Research and Development Board and the development of a powerful MOD Central committee structure dealing both with military requirements and with the research and development needed to meet them. The new headquarters organisation is designed to spread the previous tasks more evenly and thereby to allow more support for CS(RN) in the overall supervision of the Naval Research and Development programme.

Top Management

The previous posts held by CRNSS and DNPR have lapsed, and at the highest level under CS(RN) there are now two new posts, each directly responsible to CS(RN). These are the *Deputy Chief Scientist (Navy)*—DCS(N)—who is also the Head of the RNSS, and the *Chief of Naval Research*—CNR.

The DCS(N) will carry out the same function as CRNSS as regards management of the Navy's scientific manpower, but he will hand over to CNR the direction of the laboratories formerly responsible to CRNSS; this will leave him free to assist CS(RN) in matters concerned with the overall R & D programme, in scientific analysis of operational requirements, and in matching the resources, both of manpower and money, to the needs of the programme.

The CNR will assume responsibility for the former departments of Physical and Materials Research and for the CVD organisation, together with the research laboratories formerly concerned with these departments. He will also become responsible for the Senior Psychologist (Naval) and his staff. He will be charged, as CRNSS was before, with surveying the whole field of scientific research in the interests of the Navy and with collaborating with other voteholders in the planning of their research activities and the co-ordination of these with his own programmes.

Department of Deputy Chief Scientist (Navy)

The DCS(N) will be responsible for the Superintendent of Scientific Personnel—SSP(N)—operating as before, and for the former DOA (N), now to be known as the Director of Naval Operational Studies (DNOS). DNOS will preserve his previous links with the Defence Operational Analysis Organisation.

DCS(N) will also have a new Division of Naval Research and Development Administraion (DNRDA), which will combine the former RDF(N) Division and parts of the DRDS(N). The new division will be concerned with overall programmes, financial management and control, administration of international collaboration in Research and Development and with collaboration with other Government Departments and national authorities. It will also be responsible for patent work, information services and other general scientific services formerly carried out by DRDS(N). Finally DNRDA will undertake general administrative secretariat duties for CS(RN)'s headquarters and outstations, working to CNR where appropriate.

The new division will contain both scientific and administrative staff; in due course its Director will be an Assistant Secretary who in addition to his responsibilities to CS(RN) will have a line of responsibility through the appropriate Under Secretary to the Accounting Officer. In this way the concept of mixed administrative and scientific manning, pioneered in RDF(N) has been developed to bring the appropriate administrative responsibilities within Scientific Headquarters itself.

Under the new arrangement DCS(N) will have under his direction sectors responsible for operational analysis, for recruitment, training, promotion and allocation of scientific staff, for R & D finance, and for collaboration with other UK authorities and with foreign defence organisations. He will therefore be well equipped to keep under review the overall balance and justification of the Naval R & D programme and to develop a rationale for allocation of resources which is more responsive to the changing needs of the Navy.

Department of Chief of Naval Research

Under CNR will be three Directors corresponding to the former posts of DMR(N), DDNPR, and DDNPR (CVD). For the time being these will be respectively known as the Directors of Materials Research, Physical Research and CVD, but there may be some alteration in the boundaries of their fields of interest to allow a more effective combined team. The incorporation of the Senior Psychologist and his staff will also bring together under common management psychological, physiological and other scientific aspects of personnel research.

In co-ordinating the overall Naval research programme, CNR will need to consult closely with other responsible authorities, and particularly with Director General Ships and Director General Weapons. In addition to discussion with the Director-Generals themselves CNR will chair a small Research Co-ordination Committee which will include Director, ASWE, Director, AUWE and Scientific Adviser to DG Ships.

CNR will also be responsible for organising the Navy Department Research Review, whereby CS(RN) reviews the whole Navy Department Research Programme each year and makes a report to the Defence Research Committee. It has already become clear that this review will need to be a continuing sequence of events rather than a single isolated exercise each year, and this trend will be all the more necessary because the Defence Research Committee will in future require to see the whole research programme arranged in convenient packages and will require an explicit justification of objectives and plans for each element.

The RNSS

DCS(N) will act as Head of the RNSS; this will mean that CS(RN), while still being vitally concerned with the activities of the scientific service, will retain the freedom to maintain cognisance of research and development carried out by other professional staff in the Navy Department. As Head of the RNSS, DCS(N) is responsible for organisation and control of the Royal Naval Scientific Service and for advising on its manning. As regards the management and welfare of scientific staff, he will carry out precisely the same functions as CRNSS before him and all members of the RNSS should feel free to consult or appeal to him as they may feel necessary.

THE S.I.N.S. GYRO TEST CENTRE AT THE ADMIRALTY COMPASS OBSERVATORY

SUMMARY

The recently-installed S.I.N.S. Gyro Test Centre at the Admiralty Compass Observatory is described by reference to the functional requirements and uses of such an Ultra Precision Test Equipment.

J. Preston, B.Sc., Ph.D., R.N.S.S. and
J. H. Norton, B.Sc.(Eng.), R.N.S.S.
Admiralty Compass Observatory

Introduction

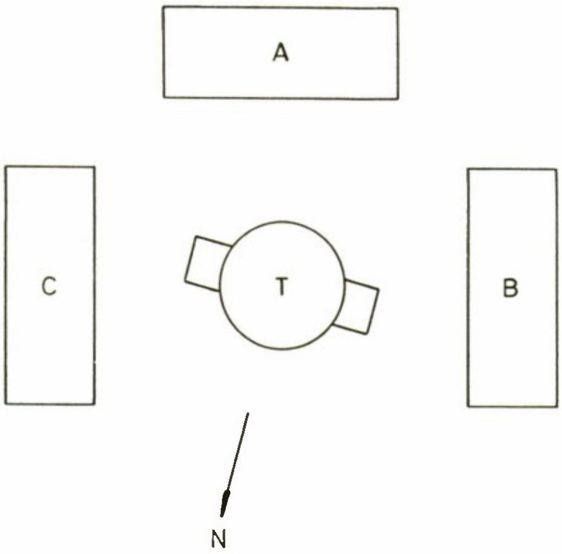
A Ship's Inertial Navigation System (S.I.N.S.) is based on gyros of the highest order of accuracy attainable. The Royal Navy's S.I.N.S., developed at the A.C.O., uses single-degree-of-freedom rate-integrating floated gyros of the type originated by Professor Draper of M.I.T. [1, 2, 3, 4]. For S.I.N.S. to be useful its gyros must have accurately known and constant parameters with extremely low random and time-variant drifts. Production testing and selection of these gyros calls for high quality instrumentation capable of accurately measuring the important parameters. Such equipment is in use at the British Aircraft Corporation's factory at Stevenage, where the gyros are made. Similarly, high quality assessment plays a major role in the development and optimisation of the design of gyros. To this end the United States Navy commissioned an American gyro manufacturer, Nortronics, a Division of the Northrop Corporation, to design and produce gyro test equipment of the highest attainable accuracy. This work resulted in the birth of the so-called Ultra-Precision Test Equipment, affectionately known as "UPTE" despite later attempts to introduce more sophisticated names. The first two installations of this equipment were at Nortronics' own Plant at Norwood, near Boston, Mass., and at the U.S. Naval Applied Science Laboratory, Brooklyn, New York. The third UPTE was ordered for the A.C.O. in October, 1966 and duly installed in July, 1967.

The photograph (Fig. 1) shows a general view of the A.C.O. installation. Fig. 2 indicates the relative positions of the three electronics consoles and the servo table.

Methods of Gyro Evaluation

Single-degree-of-freedom gyros are put to a variety of uses, in aircraft, missile and space applications as well as in S.I.N.S. Each application dictates a different set of environmental conditions and has its own requirements of magnitude and stability of sensitivities and drift parameters. Laboratory methods of evaluation must reflect these conditions and be capable of revealing the parameters required to the necessary degree of accuracy. Two species of test method may be defined as "service" and "featherbed". Service tests are designed to show how the gyro may be expected to perform under conditions of vibration, acceleration, quick warm-up, low temperature or any other

FIG. 1. The Admiralty Compass Observatory's S.I.N.S. Gyro Test Centre.



A.B.C. — Electronic Consoles
T.— Air Bearing Servo Table
FIG. 2. The Layout of UPTE.

environment peculiar to the system in which the gyro will be used. In contrast, featherbed tests are designed to show the full capability of the gyro if used under ideal conditions. The results of such testing give an upper limit to the performance which may be expected in service, and as such are much favoured by gyro manufacturers. But parameters determined in a vibration-free, temperature-controlled laboratory may bear little relation to those operating in, say, a shaking, accelerating, temperature-fluctuating missile. In S.I.N.S., however, where the very best performance is demanded from the gyros, steps are taken to provide as near ideal system conditions as possible. Certainly there are no violent changes of environmental temperature and quick warm-up is not a vital requirement. Vibration and acceleration levels are considerably lower than in many other applications. If, due to vehicle vibration, gyro performance in service proves to be markedly degraded below that obtained under ideal conditions, and if this degraded performance is unacceptable, then the most promising line of approach is likely to be to filter out the vibration rather than to attempt to re-design the gyro to withstand it. For S.I.N.S. gyros, therefore, "service" and "featherbed" become virtually synonymous.

All featherbed testing of gyros is based on one of two null-seeking servo modes, the so-called table servo and rate-loop servo. In the table servo mode, the gyro is the control element of a single axis stabiliser involving a motor-driven platform. Gyro performance is assessed and the various parameters determined by a study of how closely the stabilised platform follows the known ideal pattern of rotation rates. In the rate-loop servo mode, the gyro controls its inner gimbal position at null by means of a torque generator current. Drift parameters are determined in terms of the variation of this current. By suitable orientation of the gyro, using one or other basic mode, it is possible to derive the drift coefficients, to calibrate operational parameters and to assess the gyro's overall performance expectation when fitted in S.I.N.S.

Test Station Requirements

The basic requirements of a good quality test station may be listed:

(i) *Gyro environment*. The first essential in featherbed testing is to produce the featherbed. A temperature-controlled, semi-clean laboratory with a vibration-free massive block isolated from the building is needed. Provision must be made in the equipment itself for maintaining close control of the immediate environs of the gyro under test.

(ii) *Servo axis freedom*. In order to achieve good servo control with faithful response to gyro idiosyncrasies, special steps must be taken to reduce servo axis friction. Air bearings are considered essential in the best systems.

(iii) *Gyro supplies*. Clearly the energization of spin motor, signal pick-off and other circuits must be of high quality and controllable.

(iv) *Monitoring facilities*. It is essential to show that "constant" functions remain constant throughout a test. Many changes in indicated gyro performance have left the operator in doubt about the stability of his supplies. Without monitoring facilities there is always a suspicion that the test gear, rather than the gyro, is being tested.

(v) *Read-out system*. The test station must have chart recorders, digital print-out or other devices for presenting the required information in suitable form.

(vi) *Calibration*. Accurate work requires more than internally relative values and for full confidence to be placed in results the test equipment must be capable of calibration against sufficiently reliable standards.

(vii) *Versatility*. A test station forming part of an R and D facility should be capable of evaluating any single-degree-of-freedom gyro, or any device which may be used in the same way, *e.g.* a free gyro or a ring laser. Furthermore it should be able to produce all the gyro parameters needed by the S.I.N.S. designer and user—and a few more they haven't yet called for. Such an "all-singing, all-dancing" test station would be out of

place in a production run where single-purpose test stations prove to be more suitable.

Meeting the Requirements with UPTE

The test station requirements listed above are met as nearly perfectly as at present possible by UPTE. The most convenient way of describing the facility is by showing in some detail how these requirements are met.

(i) *Gyro environment*. The period in which the detailed specifications for UPTE were being discussed with the manufacturers coincided with the designing and building of the new Laboratory Block at the A.C.O. Thus one of the rare occasions arose when it was possible to design the laboratory for the job intended. The laboratory measures 30 by 20 ft. with double glazed windows and a temperature-controlled air conditioning plant. UPTE occupies half the space with other, less-sophisticated test stations in the other half. As shown in Fig. 2, three electronics consoles are grouped around the Servo Table. This table is a massive object (weighing $2\frac{1}{2}$ tons) standing on a 25 ton concrete block, 8 ft. square in plan and extending to a depth of 6 ft. below floor level. Fig. 3(a) shows the arrangement by which the block and table are isolated from the building. The sub-soil is gravel, which gives good attenuation of ground-borne shock waves. Thus the effects of local and distant disturbances are minimized. The sensitive level-indicators of UPTE have so far only been affected by tree-felling in the surrounding park and by earthquakes in Turkey. On the whole the featherbed would appear to be a comfortable one.

Fig. 3(b) also shows the position of a gyro under test in the table. The gyro is covered by a large metal dome, the Table-Top Temperature Chamber (T.T.T.C.), which has a magnetic amplifier proportional temperature control system and variable speed fan capable of maintaining gyro ambient steady to 0·1°C. The dome may be sealed in order to study gyro performance under reduced or increased external pressure.

(ii) *Servo axis freedom*. At the heart of the system is the Servo Table. This is an American Optical Company (formerly the Fecker Corporation) Type 252, based on the famous Model D Turntable designed at M.I.T. As shown in Fig. 3 it has a massive base, yoke and gimbal which are all made of Meehanite. The gimbal can be turned manually to any position in azimuth or elevation on

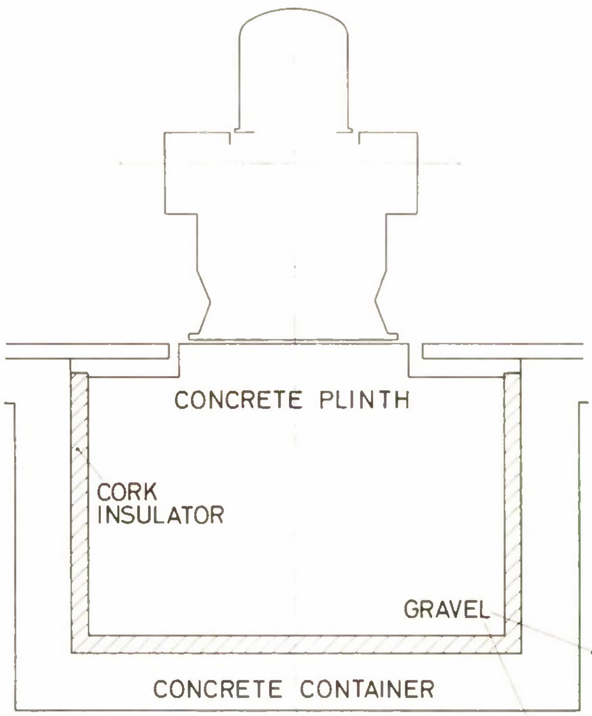
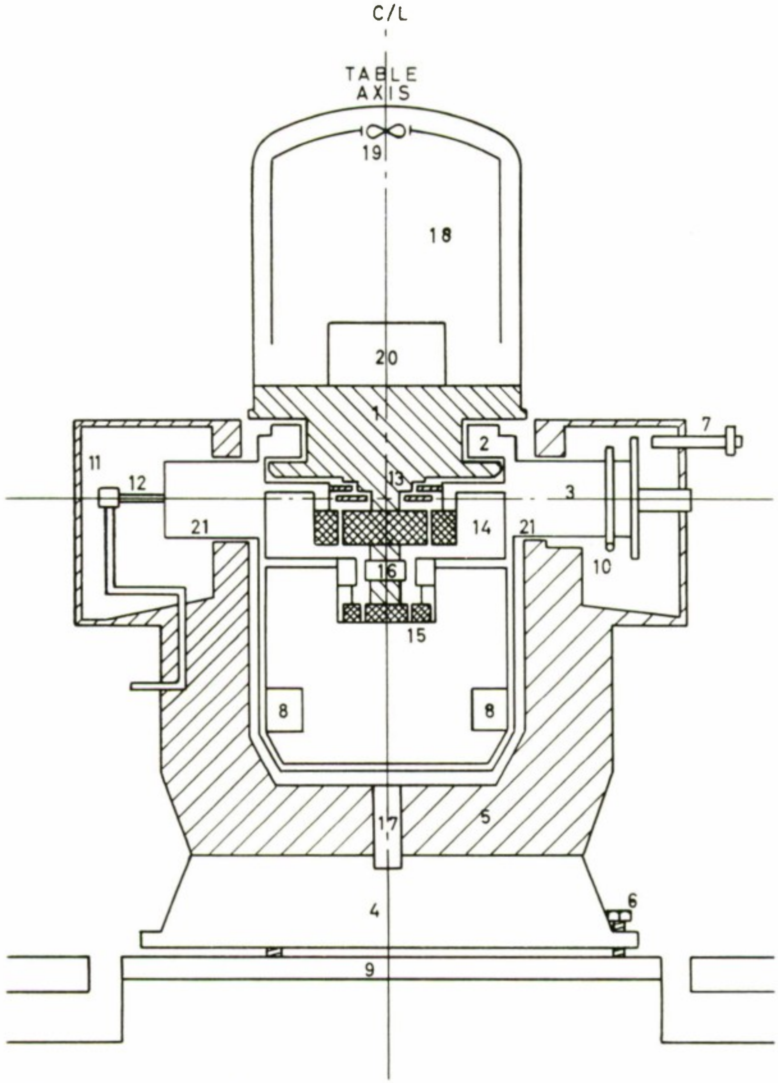


FIG. 3(a). UPTE vibration isolation mount.

roller bearings. The servo platform, which is continuously rotatable, is supported on hydrostatic air bearings pressurized to 85 p.s.i.g. A total of 36 orifices provide a journal bearing and an opposing pair of thrust bearings, having a load capacity of $\frac{1}{2}$ ton. Table drive is by an Inland Controls 35 lb. ft. D.C. torque motor without gearing. Also linked to the servo-axis is an Inductosyn 720-pole angular pick-off and a D.C. tachogenerator. Apart from the essential slip rings for the Inductosyn rotor, there is no frictional contact between the base and the air-supported stable platform. Connections to the gyro and table top are made through a flexible cable hanging from an overhead junction box. In this way servo-axis freedom is assured and extremely low rates of turning can be smoothly achieved.

The British-built air supply system, schematically shown in Fig. 4, deserves mention. Since it is hoped to maintain an unbroken air supply to the Table for periods of six months or more, a twin compressor system has been installed. These are Broom and Wade type CAR 26 carbon ring oil-free two-stage compressors delivering 16 s.c.f.m. with a working pressure of 150 p.s.i.g. Each



KEY

1. Turntable
2. Air bearing assembly
3. Gimbal
4. Base
5. Yoke
6. Levelling screws (three in number)
7. Gurley Unisec Readout
8. Counter weights
9. Base plate
10. Wormgear for rotation about trunnion axis
11. Swivel union
12. Journal and thrust air supply pipe
13. Inductosyn
14. Torque motor
15. Tachometer
16. Slip ring assembly
17. Jack assembly for Yoke rotation
18. Table top temperature chamber
19. Fan
20. Gyro
21. Trunnion axis bearing

FIG. 3 (b). The Servo Table.

compressor is put on duty for one week, with the other one on stand-by. Pressure switches control the running cycle of the duty compressor and bring in the stand-by in case of emergency. After cooling, the compressed air is fed to a receiver and thence from the compressor house into the laboratory by a long run of copper piping. A Pall activated alumina air drier reduces the water content of the air to $-90^{\circ}C$ dew point, as measured by a Shaw moisture meter. After passing through a pressure regulator and a Millipore 1 micron absolute filter, the air is temperature controlled and finally reaches the Table. Failure of the air supply or a rise in dew point above $-40^{\circ}C$ rings an alarm.

An important part of the servo system is the amplifier. This is an Inland Controls type 101F designed specifically for controlling this type of Table from inputs generated by a wide variety of gyros. An American Optical Position and Rate Command Unit may be used, instead of a gyro, to generate control signals. Accurate positioning of the Table to fractions of an arc second, or more usually a steady rate Table drive can then be achieved. Selected multiples of earth rate (from $1\times$ to $200\times$) are available, with higher uncalibrated rates. To achieve accurate rates a synchronous motor fed from a sidereal time source drives a resolver to which the Inductosyn is slaved via the Table drive system.

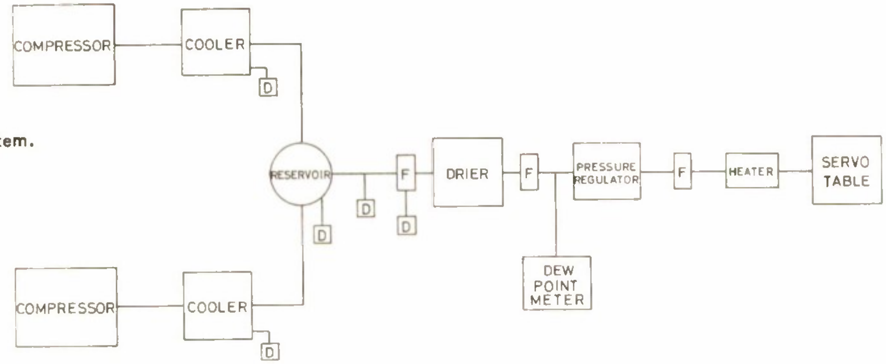


FIG. 4. The compressed air system.
F — Filters
D — Water Drains

(iii) *Gyro supplies.* A gyro requires continuous and controlled energisation of its wheel (sine or square wave, 2 or 3 phase A.C.) signal pick-off (sine wave single phase A.C.) gimbal suspension (sine or square wave single phase A.C.) torque generator (controlled D.C. levels or pulse patterns) and heater (proportionally controlled A.C. or D.C.).

In UPTE all gyro frequencies are locked to a 3MHz Motorola crystal known to be accurate to 2 parts in 10^{10}. Thus the System Time Reference (a digital clock) is accurate to 1 second in 150 years. This clock generates minutes and hours pulses giving time markers on all charts and initiating the appropriate digital prints.

A Krohn-hite polyphase power unit provides the gyro wheel with closely controlled sine wave 2 or 3 phase power at 400, 800 or 1,200 Hz. 25 VA per phase is available continuously with double power for short duration wheel starting requirements. The output is adjustable in 0·01 volt steps from zero to 120 volts. A Krohn-hite single phase power unit with similar characteristics provides signal pick-off and gimbal suspension energization at 1, 4·8, 5 or 10 KHz.

Constant currents for the torque generator are produced by a Julie Research Laboratories Ultra Stable Current Supply capable of delivering up to 100 mA controlled to better than 1 p.p.m. over long periods. Stabilization is achieved by comparison of the potential developed across a standard resistor with the e.m.f. of a standard cell at the input of the high gain chopper amplifier producing the current. A similar supply delivering 200 mA maximum forms the basis of the Nortronics Pulse Torquing system, in which closed or open loop modes may be employed with selected pulse heights and widths. Widths are adjustable in $\frac{1}{3}$ microsecond steps, locked to the Motorola frequency standard.

The final gyro requirement is temperature control. For this purpose a British Aircraft Corporation gyro temperature controller is used. This was developed specifically for use with the British S.I.N.S. gyro and is capable of maintaining a gyro temperature steady to better than 0·01°C.

(iv) *Monitoring facilities.* In the interests of being convinced that the gyro alone is responsible for the results ensuing, UPTE is endowed with a considerable capacity for monitoring. An 8-channel Brush pressurized-ink recorder, with variable gain pre-amplifiers, is used to monitor continuously eight functions which should remain constant throughout a given test. These are normally input mains and stabilized mains voltages, supply voltages to the wheel (phase A and C), the pick-off and Inductosyn, wheel power and servo null voltage. To achieve a high sensitivity in these monitors, Nortronics zero-suppression devices are fitted which accurately back-off the major part of the function. For example the wheel phase voltage monitors are normally run with 89·9 volts suppressed, allowing the 5 cm full scale chart record to correspond to 0·2 volt. In this way variations of 0·005 volt in 90 may be easily detected.

In addition to the Brush recorder for monitoring functions expected to remain constant to a high degree of precision, Varian six-inch chart recorders (of the pressure-sensitive paper type) monitor continuously:

the Constant Current Generator output (chart sensitivity 4 parts in 10^6/inch)

Gyro environmental temperature (0·05°C/inch)

Table air supply temperature (0·1°C/inch)

Table level in the E-W and N-S planes, based on Taylor-Hobson Talyvels (10 arc sec/inch).

A small recorder forms part of a Hewlett-Packard VLF comparator giving a record of phase difference between the 60 KHz transmission of M.S.F., Rugby (received via a loop antenna on the roof) and the Motorola frequency standard. Any selected frequency may be monitored by a Hewlett-Packard counter and digital print-out. Since all gyro supply frequencies are locked to the system standard there is no point in monitoring these against the less accurate crystal in the counter. The usual duty of the counter is to monitor the Table Rate Command side-real crystal against the system standard.

For occasional meter-checking a large number of test points is arranged at the Table top. These are rarely used, except for fault diagnosis and setting-up, since the connection of test leads would cause mechanical disturbances of the servo-controlled platform.

A prime requirement of a high precision installation is that the constant currents, used for torque generator energization, should be accurately known. Although the Julie Constant Current Generator maintains an empirically pre-set current steady to within 1 p.p.m., the absolute magnitude of that current must be determined by other means. For this purpose banks of Eppley saturated standard cells and resistors provide references. These are immersed in a large oil bath temperature controlled at $28{\cdot}0 \pm 0{\cdot}02$°C. A Julie high precision potentiometer and potential divider complete the D.C. measuring system, which has an accuracy of 0·1 p.p.m.

To complete the profusion of monitoring equipment, UPTE is fitted with Hewlett-Packard Valve Voltmeter, Digital Voltmeter with print-out and Oscilloscope with camera. With such a wealth of information on the stability of gyro supplies and environment, the operator may begin to have confidence that what he calls "gyro performance" is just that.

(v) *Read-out system.* Different test modes require different read-out methods. There is no point in attempting to time table rotation over 10 degree intervals if the gyro is being compensated to hold the table stationary. Conversely, attempts to chart record table position will be fruitless if the loop is subject to an earth rate command. UPTE has the ability both to time table rotation and to record table position.

Both read-outs are developed from the Table's 720-pole Inductosyn. This is energized at 10 KHz from the Position and Rate Command unit which also houses pick-off resolvers linked to the Inductosyn. These give cross-over points at each half degree of table rotation, and yield a display of Table position on a 10 inch precision vernier dial and a meter calibrated in arc seconds. The demodulated Inductosyn output is linear over ± 3 arc minutes about each null and is in a form suitable for display on an Esterline-Angus recording milliammeter or the Hewlett-Packard D.V.M. Three sensitivity ranges are available giving fractions of an arc minute for full scale recorder deflection. To prevent loss of information by off-scale readings an automatic Inductosyn re-null device operates. As full scale is approached the earth rate drive is engaged to re-position the resolver rotor in the Position and Rate Command unit. This is effectively a phantom follow-up system which in no way affects the Table or the test in progress.

For operations in which the Table is not held to a nominal zero, the Inductosyn null points are used to trigger a timer slaved to the standard frequency source. The times elapsed between successive 1, 10, 36 or 360 degree marks are displayed and printed in units of 0·1 milli-second with a maximum total error of 0·012%. One slight disadvantage of the Inductosyn read-out system, in contrast to an optical device, is that there is no unique Table zero. Each null reading is a mean of all 720 cross-overs. Ambiguity is avoided, however, since the outer rim of the 26 inch Table top is marked in $\frac{1}{2}$ degrees, with a vernier reading to 1 arc minute. Small movements of the Table through accurately repeatable angles are made possible by the use of a pair of adjustable stops and a friction clamp toggle, resulting in a useful facility for calibrations involving small angular movements.

Other read-outs are necessary in some tests which are not related to Table angle or rotation rate. For example, when the gyro is subjected to pulse torquing it is necessary to have a record of pulse counts in selected time intervals. This information is printed as required. Again, when UPTE is run in the gyro rate loop rather than the Table servo mode, the Esterline-Angus recorder may be used to record torque generator current. An electronic integrator is useful for the amplification of very small varying currents, and can be read, discharged and re-started at the command of pre-set timers.

(vi) *Calibrations*. Although UPTE has facilities for cross checking and internal relative calibrations, it is essential that the internal standards be compared with International standards. The UPTE frequency standard is being monitored continuously against the MSF transmission. Published figures show that this in turn is checked against the N.P.L. caesium standard and is rarely in error by more than two parts in 10^{11} Frequency, and therefore time, is the easiest of functions to calibrate. It is a pity that an antenna cannot be erected to receive standard cell calibrations. UPTE has duplicate banks of standard cells and resistors each with a calibration certificate from the National Bureau of Standards, Washington. It is intended to send the non-duty set to the N.P.L. for re-calibration on a regular basis.

In all types of test and usage the gyro is subject to an input due to the earth rate component along its input axis. It is important for accurate testing and calibration to know exactly what this component is. This is equivalent to stating that the direction of the earth's axis, and the angle between it and the gyro input axis in any test, must be accurately known. An uncertainty of 1 arc minute could result in errors of 0·003 deg/hour in an input axis vertical drift run. To achieve alignment accuracy of the Table axis, and the gyro input axis, an optical window suitably positioned in the laboratory roof allows direct sightings of the Pole star to be made. The elevation of Polaris, determined by theodolite, gives an accurate value of latitude, whilst from the same sighting, northerly heading is transferred directly to the Table via an optical cube.

(vii) *Versatility*. Although there are only two basic modes of operation, there are numerous ways in which conditions can be varied to produce information of the particular type required. The servo-axis is capable of orientation in any direction with respect to the earth's axis. The controlled member may be driven at a variety of speeds, held rigidly steady or slaved to the gyro output signal, and the gyro may be subjected to calibrated variations of supply and environmental conditions. A wide choice of supplies gives UPTE the capability of handling any known single-degree-of-freedom gyro. In fact UPTE comes very close to being the all-singing, all-dancing equipment of the gyro engineer's dream.

The Uses of UPTE

By way of example of the methods of operation of UPTE, Figs. 5 and 6 show functional block diagrams for two major test modes. In each case supplies and read-out devices are depicted by rectangular blocks, and monitoring systems by circles. For completeness, alternative read-outs are given where applicable.

The test illustrated by Fig. 5 is the Input Axis Vertical Drift mode, in which the Servo Table is slaved to gyro output in a null-seeking servo. In this attitude the gyro is subject to an input due to the vertical component of earth rate (approximately 11·7 deg/hour at the latitude of A.C.O.) which would normally result in the rotation of the Table with respect to the earth. By the injection of steady D.C. levels, or pulse trains, to the gyro torque generator, the Table rate may be reduced to zero or set to some other desired value. Resulting Table motion may be recorded on the Esterline-Angus chart recorder and D.V.M. (for nominally zero rates) or on the American Optical Position and Rate Read-out (for non-zero Table rates). This mode is a popular one since Table balance is unimportant and since the gyro does not see any change in gravity orientation. Long term gyro drift may be studied by adjusting the constant current to the torque generator to balance the earth rate input. Subsequent Table movement gives a measure of drift. Alternatively, constant currents may be selected to result in Table rotation rates of say 20, 10, −10, −20 deg/hour. Time intervals for successive degrees of rotation give information from which torque generator scale factor and input axis misalignment may be determined. By using the same circuit connections and merely re-positioning the Table servo-axis in certain cardinal directions, the magnitudes of all the gyro unbalance coefficients may be determined. This mode is also most suitable for the study of the effects of changes in gyro supply and environmental conditions.

Fig. 6 illustrates the arrangement for the test known variously as the Polar axis, Tumble or Torque to Balance mode. In this type of test the gyro output, rather than input, axis is aligned parallel to the Table axis and the gyro is connected in rate loop, *i.e.* the gyro output signal is amplified to provide torque generator current to hold a null signal. This current gives a measure of the input rate to the gyro plus any gyro drift. In the attitude illustrated, however, in which the output axis is parallel to, and therefore input axis perpendicular to the earth's axis, the gyro is not subject to any earth rate input. Torque generator current is then a measure of gyro drift alone. It is customary in this test to drive the Table for several revolutions clockwise and then counter-

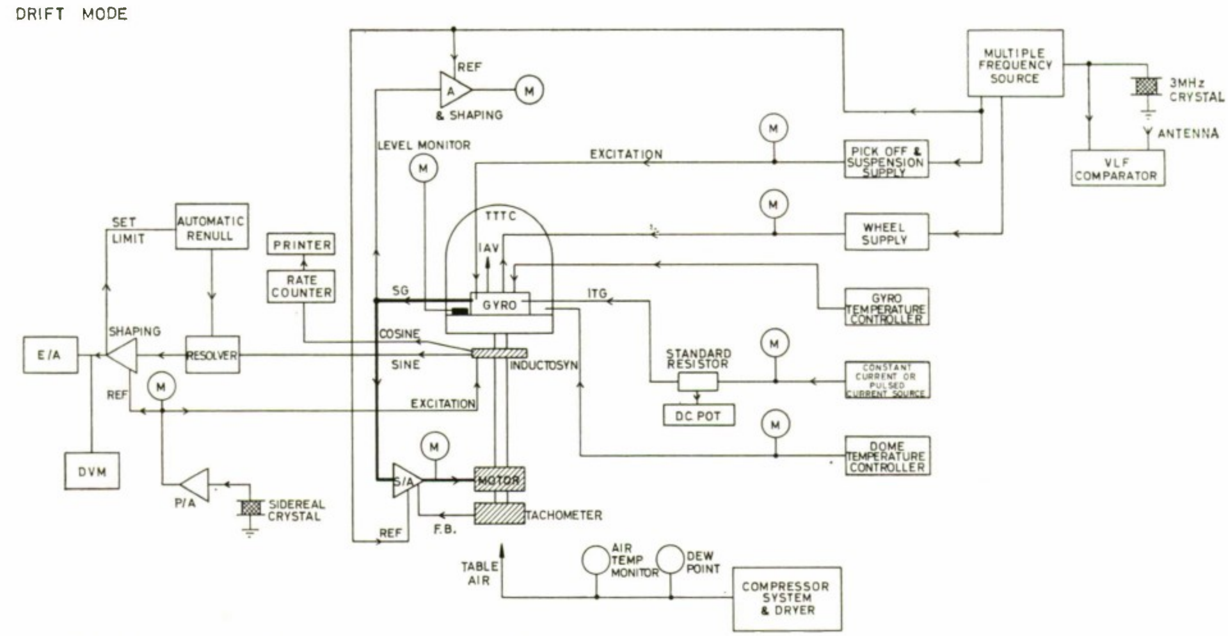


FIG. 5. Functional block diagram: Input axis vertical Drift Test.

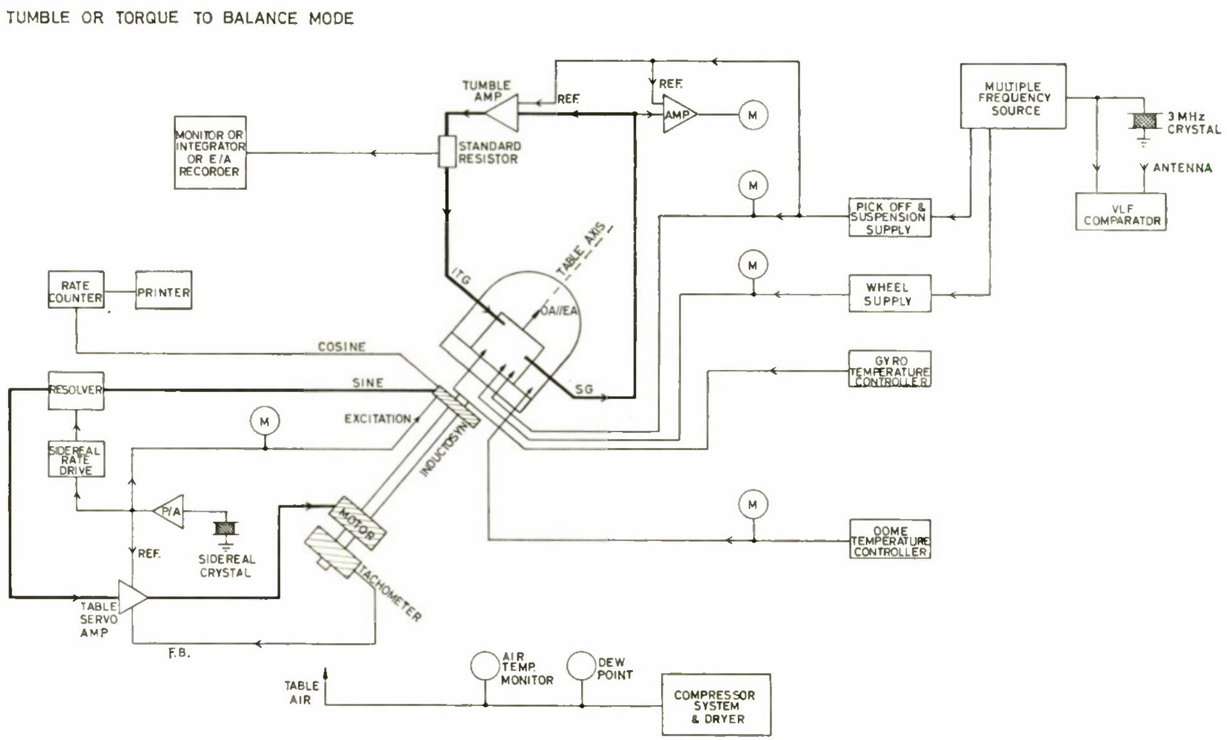


FIG. 6. Functional block diagram: Output axis parallel to Table axis Tumble Test.

clockwise at about 120 deg/hour. The recorded torque generator current not only yields values of gyro parameters for each revolution but gives a measure of how stable these parameters remain from one revolution to another. This is a relatively rapid test useful as a check of parameters, although it is somewhat unrealistic from a user's point of view.

There is so much not yet understood about S.I.N.S. gyro performance that UPTE can look forward to continuous use. The study of the effects of variations of gyro and ambient temperatures, of draughts and magnetic fields, high and low pressures, cold storage, shelf life, stability of torque generator scale factors and mass unbalance coefficients, unbalanced wheel voltages, eccentric gimbal suspension, high-rate torquing—these and many other items struggle for a place in the priority list for time on UPTE.

Acknowledgements

It is a pleasure to acknowledge the invaluable contributions made by many colleagues at the A.C.O. at all stages of the UPTE procurement and installation project, by the M.P.B.W. for work on the laboratory and essential services, by the Nortronics teams who designed, manufactured and installed the equipment, by the suppliers and fitters of the compressed air system and by the heavy lifting experts who handled the precious cargo like eggs.

References

(1) Draper, C. S., Wrigley, W. and Grohe, L. R. "The Floating Integrating Gyro and its Application to Geometrical Stabilization Problems on Moving Bases", *Institute of the Aeronautical Sciences. S.M.F. Fund Paper No. FF-13.* (1955).

(2) Savet, P. H. (ed) "Gyroscopes: Theory and Design", McGraw-Hill (1961).

(3) Heal, H. T. "Shipborne Inertial Navigation Systems", *J.R.N.S.S.*, **14** (Nov. 1959) 259.

(4) Preston, J. "Dimensional Stability Requirements in Precision Gyroscopes", *J.R.N.S.S.*, **20** (March 1965) 2.

A. B. WOOD MEDAL AND PRIZE

The Institute of Physics and The Physical Society have announced the establishment of a new Award to be known as the

A. B. WOOD MEDAL AND PRIZE

The Award will be made for distinguished work in physical sciences associated with the sea and particularly underwater acoustics.

Candidates must be under 30 years of age in the year of the award and be citizens of the United Kingdom or the U.S.A.

The Award, which will be annual, will consist of a silvergilt medal, a parchment scroll and a cash prize of 25 guineas.

Albert Beaumont Wood, O.B.E., D.Sc., R.N.S.S. died in July 1964 after a career of nearly 50 years in Naval Science during which time he was responsible for numerous distinguished innovations and developments in physical measurements and equipment relating to the sea.

In 1965 it was proposed by former colleagues on both sides of the Atlantic that there should be a memorial to Dr. Wood and a sum of money was collected for this purpose. Subsequently the Council of the Institute and Society was asked by C.R.N.S.S. to adminster the Award and this was readily agreed.

THE INTERNATIONAL ELECTROTECHNICAL COMMISSION

Its Purpose, Organisation and Procedures

H. Lewis, R.N.S.S.
Services Valve Test Laboratory

Not infrequently, a reference to the letters "I.E.C." evokes the question—"What is I.E.C., what does it do and what is the value of its work?" The short answer is that I.E.C.—The International Electrotechnical Commission—is an organization whose function is to co-ordinate the production and publication of documents on subjects in the field of electrotechnology with the aim of achieving unification of, and hence rationalization of, similar products as manufactured and used among its member countries.

The need for rationalization and unification of equipment, machines and their component parts in the present day world is a subject which gives rise to differing points of view and argument according to the needs and experiences of users. All such arguments have their elements of logic but there is little doubt that, for the purpose of construction and maintenance of equipment for world-wide use, there is a sound case for being able to obtain any component part in any locality with the knowledge that such parts will fit and work. This aspect applies equally to both military and industrial supply and maintenance organizations wherever they are located. If maintenance components are not readily available on the spot at a given moment of need, it is obviously advantageous to be able to obtain a useable, interchangeable part from other local sources.

It is hoped that the following outline description of the activities and procedures of the Commission will indicate what is involved in the considerable amount of work being undertaken by I.E.C. in this respect. The information given is based on experience gained largely in one specialized field and therefore the practices and procedures described may not be the same as those for other fields where different procedures may be more appropriate.

The Commission

The International Electrotechnical Commission was founded in 1904 and its first formal statutes were prepared and adopted in 1908. In 1947 it became affiliated—as the Electrical Division—with the International Organization for Standardization (I.S.O.). The statutes and rules of procedure were revised and expanded in June 1949 and with minor amendments continue to-day. There are at present some 40 member countries of I.E.C. from all parts of the world.

The object of the Commission is "to facilitate the co-ordination and unification of National Electrotechnical Standards not already covered by any other recognized international organization." This is achieved by the preparation and publication of documents in the form of "recommendations." These express as nearly as possible

"an international consensus of opinion on the subject aimed at harmonizing the national standards of member countries so far as conditions will permit". Such documents are recommendations only; they are not usually useable as purchasing specifications, and are intended to "assist technical understanding and agreement between a manufacturer and his customer".

The Central Office of the I.E.C. is located in Geneva, Switzerland. The overall operation of the Commission is administered by a Council of National representatives. The technical work of the Commission is administered by a Committee of Action which supervises the programmes and work of a group of Technical Committees of experts appointed to deal with specific subjects within the scope of the Commission. Some sixty committees have, at various times, been convened to prepare recommendations on specialist subjects within specific fields of interest. These committees are then disbanded or put in abeyance when the work within their scope is completed. Any I.E.C. member country may nominate specialist delegates to take part in these committees.

National Responsibilities

Each member country of I.E.C. has a central National body to undertake the co-ordination and supervision of its work within that country. In the U.K. the National body is the British Standards Institution. Among the responsibilities of this body is the distribution of international documents, co-ordination of national proposals and comments (usually by means of committees of experts on each subject) and general liaison with I.E.C. With the approval of the Committee of Action, such National bodies also undertake the secretarial duties for the various I.E.C. technical committees.

Technical Committee Meetings

It is usual for each Technical Committee to meet once a year. In some instances Sub-committees or smaller Working groups may be set up to meet more frequently to undertake special projects to speed up the work of a technical committee. The I.E.C. Central Office arranges an annual General Meeting which includes as many of the Technical Committees as can be accommodated at the selected location. Alternative arrangements are made for meetings of those Technical Committees not included in the programme. The activities and progress of the programmes of all Technical Committees are examined and reviewed each year by the Committee of Action when additions and amendments to the programmes are made as may be found necessary. The Committee of Action is further advised by its Advisory Committee on Electronics and Telecommunications (A.C.E.T.). This is a group consisting of the Chairmen (and their secretaries) of all the Technical Committees. It meets when necessary to discuss mutual problems on joint collaboration and any matters of organization *etc.* on which all Technical Committees and the Committee of Action should be informed.

Preparation of I.E.C. Documents

Any member country may put forward an initial proposal for a subject to be considered for publication as an I.E.C. recommendation. An outline proposal is circulated for examination by each country (*e.g.* the appropriate B.S.I. committee) so that opinions on the suitability of the subject are submitted to the Secretariat of the relevant Technical Committee. If there is a majority opinion in favour of the proposal the Secretariat issues the complete proposal as a formal document, in I.E.C. format, for detailed consideration by all member countries. The full text and any comments by member countries are then discussed at the next meeting of the appropriate Technical Committee. When the detailed text has been reviewed and accepted by the Technical Committee it is re-issued in its final edited form, by the I.E.C. Central Office for approval and ratification by the National Authorities of the member countries. This is known as a "Six Months Rule Document" because approval or otherwise must be registered to the I.E.C. Central Office within six months of the date of issue. If more than four-fifths of the member countries approve the contents and form of the document it is published as an I.E.C. recommendation. Supplies of the final publications are then made available in quantity to member countries. If and when deemed necessary, an I.E.C. publication may be revised or amended to ensure that it is kept up to date with current practice.

Some Practical Aspects and Results

The field in which the author has been involved for some time is that of Electronic Valves (now known almost universally as "Electron Tubes"). The I.E.C. committee concerned with this field, TC-39, was initiated in 1952 as one of several specialist subject committees in the field of Communications, Radar and Audio equipment. TC-39 quickly became involved in an extensive programme of requirements for "Recommendations" on all aspects of measurement on electronic valves for use in a variety of applications. The programme was at first sub-divided for convenience into two groups of work:—

(1) Preparation of compatibility data on Physical Dimensions of Electronic Valve Outlines, Basis, Caps and Holders.
(2) Methods of measurement of electrical characteristics of electronic valves.

The work on (1) Physical Dimensions was evolved from existing National data available from several countries and made very rapid progress which resulted in the issue of a document entitled "I.E.C. Publication 67—Dimensions of electronic tubes and valves." Many additions and revisions have since been made to this document and it is now a comprehensive volume containing details of almost all known data required to ensure physical interchangeability and compatibility between valves made by all I.E.C. member countries. The data contained in this publication is published nationally by most countries for their internal use. It is contained in the British Standards *B.S.*448 Dimensions of Electronic Tubes and Valves.

The work on (2) Measurement of Valve Characteristics has, not unexpectedly, been more difficult and progress has been slower. Documents on electrical measurements on receiving and transmitting tubes have been completed and issued in "I.E.C. Publication 151—Measurements of the Electrical Properties of Electronic Tubes and Valves ". Fifteen sections have already been published.

(a) Precautions relating to Methods of Measurement.
(b) Methods of Measurement on:—
1. Electrode Currents.
2. Heater or Filament Current.
3. Equivalent Input and Output Admittances.
4. Noise Factor.
5. Hiss and Hum.
6. Application of Mechanical Shock Excitation.
7. Equivalent Noise Resistance.
8. Cathode Heating Time and Heater Warm-up Time.
9. Cathode Interface Impedance.
10. Audio Frequency Output Power and Distortion.
11. Radio Frequency Output Power.
12. Electrode Resistance, Transconductance, Amplification Factor, Conversion Resistance and Conversion Transconductance.
13. Emission Current from Hot Cathodes.
14. Radar and Oscilloscope Cathode Ray Tubes.
15. Spurious and Unwanted Electrode Currents.

A further 10 sections are in various stages of preparation for publication, Methods of Measurement on:—
1. Corona Stabilizer Tubes.
2. Noise caused by Mechanical or Acoustic Excitations.
3. Gas-filled Tubes (General Measurements).
4. Display Tube Resolution.
5. Cross-modulation Effects.
6. Television Picture Tubes.
7. Thyratron Pulse Modulators.
8. Vacuum Pulse Modulators.
9. Gieger-Muller Counter Tubes.
10. Dimensions of new 14-pin Glass Base.

Work currently in hand by TC-39 is largely in the area of measurements on Electro-Optical and Light Sensitive Devices such as cathode ray storage tubes, light conversion tubes, photo tubes, camera tubes and alpha-numerical indicator tubes.

To further expedite the work of TC-39, a sub-committee (SC-39A) was formed in 1965 to undertake the preparation of documents on measurements of microwave tubes. The results of the efforts of this sub-committee should begin to become available during the forthcoming year. They will consist of publications similar to those listed above but applicable to the field of microwave tubes.

Other detailed documents have been prepared and published as recommendations to assist both the manufacturer and the users of electronic valves on such subjects as:—

Methods of Measurement of direct interelectrode capacitances of electronic tubes and valves.
Rating systems for electronic tubes and valves.
Standard numbering of electrodes and units in electronic tubes and valves.
Designation of deflecting electrodes of cathode ray tubes.

A further need arising from the work of each Technical Committee is that of ensuring that any subject that might be of interest to other committees is fully co-ordinated between the interested parties, *e.g.* Environmental conditions of use or special measurements to assist reliability. For light-sensitive devices, close collaboration is necessary between I.E.C. and the corresponding body (International Commission on Illumination (C.I.E.)) which deals with detailed aspects of light measurements.

Another field to which it has been found essential to give special consideration is that of standard Terms and Definitions. I.E.C. have produced an International Electrotechnical Vocabulary—

Publication No. 50. This document is issued in many separate sections each produced and agreed by the relevant specialist sub-committee. The section (07) on Electronic Valves is currently undergoing a complete review to bring it up to date. The Terms and Definitions contained in this document are a consensus of recommendations from various countries. They have been drafted with considerable care, in both official languages, in an endeavour to ensure that they are unambiguous and are fully understandable to all member countries. Thus these terms can be used, directly or by cross-reference, in technical information documents or in purchasing specifications with the knowledge that misinterpretation of the technical meaning is unlikely to occur.

All I.E.C. publications are issued in bilingual (English/French) form. Many countries obtain quantities direct from the Commission for re-sale unchanged to users. Other countries reprint the I.E.C. document in their own National form (*e.g.* B.S.I. issue some as British Standards) and these are obtainable from the sales department of the national organization. The users of these publications are sometimes surprisingly varied, *i.e.* Manufacturers and Users of electronic parts, Education bodies and similar organizations, Technical Reference Libraries and Public Service Departments to name but a few.

Use of I.E.C. Publications and British Standards by U.K. Services

In the field of electronic valves use has been made of British Standards for many years. British Services Technical Specifications and Documents have made direct or indirect use of these for features such as Physical Dimensions, Capacitance Measurements, Photometric Data, Material Qualities and Finishes *etc*. In the new system now being formulated for British Common Standards for Electronic Parts all published documents including specifications for use by the Services, will be issued as British Standards and most of the material content will be derived from detailed information originating in the work of I.E.C. Similarly, technical specifications now nearing final acceptance for military use by N.A.T.O. countries have been compiled to a very large extent from details and data contained in the appropriate I.E.C. publications.

There is no doubt that the use and application of I.E.C. Recommendations can now be shown to have resulted in appreciable unification and improvement in both equipment and parts in respect of:—

(a) Technical performance and interchangeability.

(b) Overall quality.

(c) Physical and mechanical compatibility.

(d) Environmental operation.

Achievements in these respects, although the full extent is not yet known, give at least some indication that the effort and cost involved in producing I.E.C. publications appears to be well worth while.

M. H. OLIVER, Ph.D., B.Sc., D.I.C., C.Eng., A.C.G.I., A.M.I.E.E.

Dr. Martin Hugh Oliver, Head of the Radio Department at the Royal Aircraft Establishment, has been promoted to Acting Chief Scientific Officer and appointed Superintendent, Services Electronics Research Laboratory, Baldock, Herts, as from 26th August, 1968.

Dr. Oliver began his education at Kings School, Peterborough and went from there to Imperial College, where he gained a B.Sc. with 1st Class Honours in 1935. His Ph.D. was awarded in 1939 for a thesis on "Measurements in Connection with Electrical Surge Phenomena".

During the early war years Dr. Oliver worked in the Radio Department at the National Physical Laboratory where he carried out research on radio frequency cables and the measurement of impedance and frequency.

Joining the Telecommunications Research Establishment in 1943 he became involved with the airborne centimetre "Oboe" apparatus and in the techniques of measurement of impedance and related quantities from D.C. to the highest radio frequencies. Later, he became Head of the Division concerned with the development of techniques of phase coherent integration radar.

In 1956 he became Superintendent of Microwave Electronic Research and in 1960, Superintendent, Offensive Radar at the Royal Radar Establishment. Dr. Oliver was appointed Head of the Radio Department at the Royal Aircraft Establishment in 1965.

SOME NEW COMPUTER APPLICATIONS IN THE R.N.S.S.

D. R. Jarman, B.Sc.(Eng.), M.I.E.E., C.Eng.,* R.N.S.S.
Department of Naval Physical Research

Introduction

In August 1965, a Panel was set up by Chief Scientist (R.N.) to review policy for scientific computers in the Navy Department. This Panel issued a report during 1966 in which it made certain recommendations. One of the recommendations was that a permanent review body should be set up " to supervise the future requirements of the Navy Department in this field ".

As a result of this recommendation, the permanent review body, known as the " Navy Department Scientific Computing Panel ", was set up in September 1967 and held its first meeting during October. The membership of this panel includes representatives of the major scientific computer users, *i.e.* ASWE, AUWE, NCRE and ARL, together with O & M(N) and RDF(N). The Chairman and Secretary are provided by DNPR. The terms of reference are the following:

1. To keep under continuous review the scientific computing needs of Navy Department and recommend how they are to be met. The panel should not only examine current requirements and their probable expansion but should maintain a constant survey of new developments in computer science and their likely effect on future policy. If need be it should recommend any steps it considers necessary within the Navy Department for the exploration of new techniques.
2. Scientific computing requirements within Navy Department will be referred to the panel for consideration, and if necessary co-ordination, from their earliest stages. The panel should also recommend the development and implementation of computer applications that it itself considers necessary in addition to those already included in establishment programmes.
3. Implementation of the panel's recommendations will be carried out through the normal departmental channels. It will be the responsibility of the panel to advise on financial provision for future computing requirements.
4. The panel should maintain liaison, through cross-representation, with the Navy Department ADP Committee, and through DGW(N) with programmes and practice in shipborne computers. It should also keep in touch with developments elsewhere in the Ministry of Defence and other Government Departments and with outside workers in the field.
5. The panel will be responsible to CS(RN) and its comments on major equipment proposals will be available to the Navy Department R & D Board. The Chairman will be provided from the Department of Naval Physical Research.

A further recommendation of the Chief Scientist's Panel was that the KDF9 computer at ARL, Teddington should be expanded to provide a central computer service for naval R & D establishments. In addition, it recommended that data links with this computer should be established to any user whose requirements could be met in this way.

* Secretary, Navy Dept., Scientific Computing Panel.

As a result of these recommendations, the computer has now been expanded and 10 data links have been set up or are projected. In this way, many more people than before will have access to this big machine.

Although many people in the RNSS are now using the facilities provided, it is considered that the RNSS as a whole is making insufficient use of computers for scientific work. There are many people doing laborious and time consuming jobs who could benefit very greatly by applying their jobs to solution by computer. This is now made comparatively easy by the advent of high level programming languages like Algol and Fortran. Neither the scientist nor the engineer of the future will be properly equipped for his job unless he is able to program his own problems for solution by computer in one of the standard high level languages, which are implemented on all modern machines.

As a means of reviewing new developments (paragraph 1 of the terms of reference), a special meeting was held during January 1968, at which a number of people were invited to give talks on new developments taking place in their own establishments. The following sections of this paper contain an account of what was said at the meeting on four topics, together with a general introduction to the subject of Computer Aided Circuit Design, which was inspired largely through discussions with AUWE on aspects of this subject in which they have an interest.

Computer Aided Ship Design (A.R.L. Teddington)

Dr. Yuille described the work started at ARL on the development of a system for computer aided ship design, the first phase of which was intended to be used for carrying out Ship Design Studies and which would be based mainly on existing design techniques. It was planned that the Ship Design program would operate inside the framework of a general purpose multi-access system so that the designer would be able to command from an on-line typewriter, either modifications to the data structure representing the ship (both the hull shape and the internal arrangement of the ship are stored) or the execution of one of the following calculations:

(a) Standard hydrostatic calculations
(b) Resistance
(c) Propulsive coefficients and propeller design
(d) Space analysis
(e) Weights and centres of gravity
(f) Order of cost
(g) Curves of righting moment against heel.

To avoid duplication, information had been obtained on computer aided ship design by other authorities. With the hope of ensuring eventual compatibility, particular attention would be given to the work planned by the British Ship Research Association concerning computer aids at the production end of the ship design process. The work being carried out in the USA had been reviewed recently by ARL and contact would be maintained with the several developments there.

The system was being developed on the expanded KDF9 computer at ARL using the *Egdon 3* scheme as a basis. This scheme would permit a person sitting at a teletype to assemble data and programs on a large disc file and to have these inserted into the queue of jobs waiting to be processed by the computer. All the programs would use common data regarding the shape of hull and the internal arrangement of the ship. The scheme would be extended to permit a person at a teletype to interrupt the general flow of jobs through the computer in order to have short programs run by means of simple commands relevant to ships and familiar to a designer. The new design would be produced by modifying an existing design, and having calculations made to enable the designer to assess its capabilities. Results of his operations would be shown on the teletype, printed on a line printer or drawn by a graph plotting machine.

One of the major problems was to find a satisfactory method of holding the shape of the hull of a ship in the store of a computer. ARL was investigating several possibilities, the most promising of which appeared to be a technique developed in the USA. With this, arbitrary shapes could be represented by a number of patches each of which had a bicubic, or higher order, parametric equation with coefficients expressed in terms of the coordinates, derivatives, twist *etc.* at each of the four corners. Each corner was shared by four, or two, patches and continuity across patch boundaries was assured.

Another problem was that of holding in the computer store a representation of the internal arrangement of the ship and its contents. For this purpose one needed to know the associations between the various items as well as their physical properties. A general program had been written to handle associative data in the core store of the KDF9 computer and this was being elaborated to enable it to use data occupying up to two million words on the disc store by means of a software paging supervisor. Apart from its use in the ship design project this program would have applications in other projects concerned with associative data.

The aim was to have a basic system for elementary ship design working in 1969 by means of a teletype in Bath. This would enable routine calculations and detailed design work on present types of ships to be performed, thus saving draw-

ing office efforts and freeing designers for more creative work. The major benefits hoped for were integration of the design process and considerable reduction in the time required to develop a design.

This system would then be expanded to cover many more aspects of the design problem. (There was no basic reason why it should be confined to the design of ships, but other possibilities were not being considered at present).

The ultimate aim was to provide a comprehensive set of computer programs concerned with many facets of ship design, which could be used with the minimum of effort on the part of the designer. Later, results would be displayed on a cathode ray tube and operations with a light pen would be considered. Thus the computer would provide rapid answers to the calculations involved in ship design, leaving the designer free to use his initiative, experience and judgement in producing a balanced design.

Structural Analysis (NCRE Dunfermline)

Mr. Kendrick said that the elastic analysis of structures was extremely well suited to solution by computer and that NCRE had produced a number of computer programs for the structural analysis of warships as a replacement for the approximate methods which had been used by warship designers in the past. Because of the limited capacity of the computers available, the NCRE effort to date had concentrated on the two dimensional analysis of such forms as axisymmetric structures and grillages under static loading.

The existing axisymmetric program was based on shell theory, but it was quite a sophisticated analysis catering for cylindrical, conical, toroidal, spherical and other more general shapes of constant or varying thickness. This was ideally suited to submarine pressure hull stressing, but was also useful in many other applications. The present grillage programs determined stresses in meshes of beams, which were either plane or prismatically curved. In particular the plane grillage program had been used to analyze a carrier deck under aircraft loading. The curved grillage program was an excellent approximation to the framed hull of a ship and the existing version of the program written for a small computer (PEGASUS), by making maximum use of planes of symmetry, compared favourably with the massive general purpose program STRESS (developed for an IBM computer) in the size of structure which could be analyzed.

The development and use of structural programs at NCRE has emphasized an aspect of programming which was becoming increasingly important in the adaption of large general-purpose structural programs to specialized use. This had demanded selectivity of input, which was achieved by writing a lead-in program to permit a greatly abbreviated data tape to supply all the information required by the main program. An example of this was an " arbitrary axisymmetric solids " program employing finite element techniques, which had been adapted in the first place to provide a detailed analysis of a T-frame structure with fillet welds (either internal or external to a cylindrical hull). Additional structures and sub-structures were now being similarly considered in detail by writing appropriate initial input programs.

Computer programs had also been written on the dynamic response of ships structures to explosion loading. Examples of this work were the elastic response of ships to non-contact underwater explosions and the analysis of ships superstructures subjected to air blast loading. This work was continuing and programs were now being developed to predict the whipping motions and stresses, allowing for the effort of migration of the explosion gas bubble and plastic bending of the ships main girder. A general program was also under development to estimate the pressures created when missile motors were ignited in a ship's magazine, the aim being to aid in the design of magazine venting systems.

The larger computers now becoming available would lead to significant advances in the static and dynamic structural analysis of warships. Programs written for these computers would enable three dimensional structural analyses to be made of stiffened shell structures, such as the hull-deckhouse system and the ships double bottom. This would not be limited to elastic analysis, but would be extended to non-linear, large deflection, elasto-plastic analysis of stiffened shell structures using sophisticated finite element methods. Programs would also be developed to compute the pitching, heaving, bending moment and sheer force response characteristics of warship forms in regular head, following and oblique waves, to compute the long term statistical distribution of wave induced bending and sheer, and to predict ship slamming and the alterations of ship speed and direction required to reduce it. With the aid of larger computers it was now possible to apply general programs which had become available on hydrodynamic theory to underwater explosion phenomena without introducing any simplifying approximations.

Three dimensional structural analyses had already been made in the USA; for example NASA had developed such a program which could be implemented on five of the large American computers. It was considered most important that Britain should be able to use such programs; this meant either buying American machines or pro-

ducing the necessary software for new large British machines.

In addition to developing methods of static and dynamic stress analysis, NCRE was providing design aids for use by Naval Constructors. For this type of work there was a need for good graph plotting facilities to produce structural drawings. A start had also been made to develop programs to compute an optimum design for a ship in terms of either cost or weight.

Use of Computers for Mathematics

Dr. Samet (Consultant to AUWE Portland) opened his talk by noting that computers had to date been used in research work mainly for arithmetic, with any mathematical analyses required in the research having been completed beforehand. He suggested that emphasis should now be put on using computers to carry out the manipulative mathematics, which in general was mostly algebra with some calculus. This would be beneficial to those scientists who were not good at mathematics and who made mistakes or chose wrong methods or perhaps avoided the theoretical work.

Symbol manipulation had received much attention in the past few years; but the emphasis had been mostly for compiler writing (analysis of expressions etc.) or for spectacular operations such as theorem proving. Some work had however been carried out on algebraic manipulation, etc., and there were a few programs for differentiation and integration, symbolically not numerically. This work had been mostly in the United States and had tended to be academic. The techniques used were mostly list processing and, to date, list processing languages had been available only on relatively large machines. PL/1 was the first such language to include such facilities in its specification, but even these had not been implemented. One difficulty, therefore, had been that the required techniques had not been widely available. Easy access through time sharing systems would make it a more reasonable proposition for many users to have this " machine-aided manipulation". Once users were aware of what could be done, there would be considerable pressure on software groups to provide for these requirements. This should lead to better interactive terminals than teletypes. A light pen used in conjunction with a CRT would be ideal, but was expensive. A compromise could be reached by using a CRT together with an appropriate push button panel.

One could expect to see the development of programming systems along such lines starting with the actual problem requiring a solution, performing as much manipulation and transformation as necessary and turning to numerical methods for the final solution. Dr. Samet quoted as an example the solution by computer of differential equations with given boundary conditions in terms of a series. At present, the usual pattern was to find a numerical solution of an approximate problem, rather than the numerical solution of the actual problem. In addition some problems were not really numerical at all, *e.g.* matching shapes, pattern recognition, information retrieval, etc.

Non-mathematicians who needed to use mathematics might be termed mathematics consumers to serve whom simple interative systems, like that developed by the Department of Machine Intelligence and Perception, Edinburgh University, were suitable. The user was there able to converse with a standard program, not his own, and was guided through the various stages that he required. Common applications were statistics and the like, but there is no need to limit the machine in this way. The basic problem was communication; so far, the non-specialist user had had to learn a considerable amount of irrelevant material to use a package program designed to foresee all eventualities.

Predictive Monitoring of a Human Subject in a Diving Tank (R.N.P.L. Alverstoke)

Mr. Wilton-Davies made a presentation to the panel on a proposal for using a computer in a physiological research project. He said that one of the most important problems on which research was being done at the Royal Naval Physiological Laboratory was to increase the safety of divers by developing techniques of avoiding the hazards to which they were subject, the most intractable of which was probably decompression sickness. The traditional method was to establish a table of decompression "stops" at various levels and for various times depending on the depth and duration of the dive, but in spite of much work, cases of decompression sickness still arose even when using tables based on many years of experience and research, and under strictly-controlled conditions.

Many of these cases must be ascribed to variation within the population of divers; this variation was not only between different individuals, but between performances on different occasions for the same diver. The factors which placed an individual outside the safety margin on occasions had not yet been established; it was suggested that this failure had been contributed to by a tendency of some workers to seek a single factor rather than a combination of factors. As a corollary to the occasional failure of a decompression schedule, it must follow that a schedule must sometimes be unnecessarily cautious; such occasions will not be revealed by current techniques.

There was in fact no adequate theoretical basis on which decompression tables may be constructed without risk to pioneer divers. Even the mechanism of decompression sickness had not been established; although it seemed highly probable that bubbles of gas were involved, the critical site or sites of bubbles could not be established in a given case.

Until predictions of a decompression schedule for a new dive could be made with more confidence than that justified by previous experience, it was suggested that experimental dives at least should be regulated by the response of the diver's body to the dive and to the decompression as this progressed. A casc of decompression sickness responded more rapidly and completely to the standard treatment (recompression) when this was begun early, and less well when treatment was delayed. Extrapolating from this, it seemed likely that treatment would be most effective and least prolonged if initiated before the onset of clinical decompression sickness, and even before the patient was aware of anything wrong.

This introduced the concept of predictive monitoring of the subject in an experimental dive. The technique of predictive monitoring had recently been reported in cardiovascular research, and some successful predictions of the approach of coronary thrombosis had been made up to two days before the appearance of clinical signs. Naturally, once the techniques had been established, the object was to avoid the onset of the condition under study.

It would be necessary to monitor and record as many physiological variables as possible during dives. For this type of work manual methods were vary laborious, and the use of a computer was most desirable. Off-line computer studies of chart recordings have been begun at RNPL using the d-Mac Pencil Follower to translate the tracings into punched tape. The initial study, of the intervals between successive heart-beats, already promised to provide an objective means of differentiating between physical and physiological stress. The off-line approach had advantages in the initial writing and "debugging" of computer programs because they could be tested on noise-free data without redundant values, but was very time-consuming in the translation of data into a form acceptable by a computer.

The use of a computer on-line would allow the experimenters at RNPL to form an overall picture of the subject's condition based upon simultaneous observations of a number of physiological variables, and to keep this picture up-to-date throughout an experiment. A promising approach had been suggested by Mr. H. S. Wolff of the MRC Laboratories at Hampstead. This suggestion was to take advantage of the pattern-recognition ability of the human brain. For example, an overall picture based on four variables might take the form of a displayed square when all the variables had normal values. The length of a side would represent the degree of normality of the corresponding variable, and would increase with above-normal values and decrease with below-normal values. Changes of some variables with respect to the others would distort the square.

This technique could be applied to more variables than could be considered simultaneously by the most experienced human observer in their raw form. To take an example, a human observer could be expected to detect significant changes in a displayed electrocardiogram such as variations in the P-R interval. He could not be expected to be able to tell at the time whether this interval was varying directly or inversely with the basal skin resistance. This relationship could be of value in predicting the onset of decompression sickness in time to avoid it.

Computer Aided Circuit Design

Introduction

In the field of circuit design, as in any other, a computer can be of considerable assistance in many ways. It can be used at almost any stage in the design, and its use can very much simplify the whole design process. The ways in which it can help most are the following:

(a) Repeating a calculation many times
(b) Handling a lot of data
(c) Solving a problem which is too complicated to solve by longhand methods, without making considerable approximations
(d) Evaluating the effects of changes in circuit parameters caused by component tolerances, drift, etc.
(e) Studying the feasibility and cost of circuit optimisation
(f) Simulating component failure
(g) Developing optimum physical device layouts and optimum circuit interconnection paths.

The Design Process

In designing a circuit by the normal methods, an engineer follows the following procedure:

(a) The circuit operation is defined (in terms of inputs and outputs)
(b) The method of approach is decided upon (*i.e.* the type of circuit to be used)
(c) A paper design is worked out
(d) A breadboard model is constructed
(e) The model is tested and optimised

(f) A component tolerance check is made by placing into the circuit a range of components, preferably including some at their limits

(g) If the circuit is not within specification in all cases, then steps (e) and (f) will have to be repeated, with perhaps closer tolerance components at some strategic points.

How the Computer Can Help

Many of these steps can be aided by the computer, but there are still some which can best be performed by man. It is possible to envisage a situation in which a library of standard circuits is held in the computer together with their transfer functions, and that when the circuit operation is defined, the computer makes a search for the circuit with the correct transfer function. However, man's inventive genius will usually win in this situation, and he will probably produce a much simpler circuit than the computer would. In any case, many a circuit function can only be generated by what would appear to the computer to be a new circuit, although it uses well known techniques in a new configuration.

At this stage, a paper design must be worked out as in the longhand method. This involves inserting nominal values of components and transistor types.

The construction of a bread board model is the point at which the computer comes into its own. The "breadboard" is constructed within the computer by completely defining the circuit to it in some suitable form.

The testing and optimising stage is performed by asking the computer to analyse the circuit and change component values until an optimum design is produced (for instance in terms of frequency response).

Finally, a component tolerance check is performed. This involves, for instance, a parameter sensitivity test, a worst case analysis and a Monte Carlo analysis.

Construction of the Model

The first step in the construction of the model is to select suitable transistor models to represent the active components in the circuit (such as, for instance, the hybrid-Pi circuit for high frequency work) and to fabricate the complete equivalent circuit diagram. In constructing such an equivalent circuit, it is not necessary to make any simplifying assumptions, such as are necessary in doing a long-hand analysis. This means that a much more accurate prediction of circuit performance is possible by using a computer. Having constructed such a model, the computer is now required to analyse it. For an AC or DC analysis, the circuit can be fully represented by a series of complex algebraic equations, of which there will be as many as there are unknowns in the circuit. This is where the computer really scores, because the complexity of even the simplest of transistor circuits, when represented in its equivalent circuit form, presents a formidable task in manual handling.

The computer will now handle these equations in one of the standard ways (*i.e.* by performing a Gaussion Elimination or an iterative procedure), to produce a solution in terms of the required output. This process will be repeated for a range of selected frequencies to produce the frequency response in terms of both amplitude and phase. Should the responses produced not meet the design criteria, then the engineer will need to inject certain changes into the circuit and invite the computer to repeat the above performance, this process being repeated until the output conditions are met.

In performing a transient analysis, it is necessary to represent the circuit by a series of simultaneous differential equations, which have to be solved by one of the standard numerical integration routines, such as Euler's Method or the Runge-Kutta Method.

Analysis of the Circuit

So far, the circuit design has been done on the basis of component nominal values. The next stage is to check the circuit against component tolerances (which the engineer will have set according to his past experience), in as many ways as necessary to ensure that any circuit built to this specification will meet the requirements.

A parameter sensitivity test can be devised which involves setting each of the variables in turn to both its lower limit and its upper limit, while retaining the other variables at their nominal values. For each component, the computer is asked to compute the difference between the output obtained from the upper and lower limits of the component, divided by the nominal value. This will give the sensitivity in terms of the percentage change in output corresponding to the range of each input variable. The computer can be asked to arrange these in order of magnitude. If necessary, at this stage, the engineer might wish to decrease the tolerance of some of the most sensitive components, and again repeat the test until a satisfactory result is obtained.

In order to find the spread of circuit performance to be expected from a production run on the particular circuit, it is necessary for the computer to perform what is known as a Monte Carlo analysis. Many output solutions are generated, each from a unique set of input variables which are selected randomly according to some specified distribution within the tolerances set for each component. The accuracy of the representation

depends on the type of distribution chosen for the component values. This must be chosen according to how the manufacturer selects his components. In most cases, this can be considered to be normal, but in some special cases might be rectangular. If for any set of variables, the output should fall outside the limits specified for it, then the computer must print out the complete set together with the output. The computer can also be programmed to print out a histogram plot to show the overall distribution of the output, together with mean value, variance and standard deviation. Provided sufficient solutions are formed by the Monte Carlo analysis, then the histogram plot will show the worst case that is likely to occur.

Apart from calculating the effect, on the circuit performance, of changes in component values, it is also possible for the computer to calculate the effects which changes of temperature and humidity will have on the components.

The computer can also help with the diagnosis of faults in a circuit. It is possible to build up a dictionary of faults, each with its own specific signature. This is achieved by calculating the response of the circuit at, say, three specific frequencies (*i.e.* poles or zeros) using the nominal values of components. To compile the fault dictionary, the computer must be programmed to record the effect on the response at each of these three frequencies of each component in turn becoming higher and lower than nominal (*i.e.* outside its tolerance). If the response of a faulty circuit is compared with the nominal response, the signature so obtained can be compared with the signatures in the dictionary to discover which component is faulty and whether it is high or low.

Input/Output Devices

So far nothing has been said about how the circuit information is presented to the computer. There are a number of different ways of describing a circuit in a form that a computer can use. Basically, for AC and DC analysis, the circuit will need to be described in terms of a number of simultaneous linear algebraic equations, which in turn can be described to the computer in a matrix form, which can then be solved for all the unknowns. Any sophisticated program will have its own language in which a designer can describe the circuit, and which the program will interpret into the correct form for solution. In general, the circuit description will be written on a deck of punched cards which will be input to the computer together with the program.

Most sophisticated methods include the use of an on-line teletypewriter or a cathode ray tube display with a light pen (or a combination of both). An example of this is the Massachussets Institute of Technology's Project MAC in which a circuit is drawn on the CRT with the light pen and the component values are assigned by either typing or sketching on the CRT. This is sufficient for the computer to analyze the circuit and produce waveforms and tables of information. After studying these, the designer can return the circuit to the screen and modify as necessary to produce an improved result.

The Standard Programs

There are a number of standard programs in general use, each of which has its own special virtues. None of them is best at doing everything (*i.e.* DC problems AC problems, and transient problems, both linear and non-linear), but each problem has to be considered on its merits. Two of the earlier programs will be described.

The first is called *NET1*, which was developed on a *MANIAC II* at Los Alamos and later translated for *IBM* machines. It can simulate resistors, capacitors, inductors and mutual inductors, and can handle both transistors and diodes and deal with fixed value voltage sources and several classes of time dependant voltage sources (*i.e.* sinusoidal, trapezoidal and exponential). After identifying the components and numbering the nodes, the circuit is described by four items for each element *i.e.* identifier, starting and finishing nodes and value (or transistor or diode type number). This information is punched on cards and input to the computer together with the *NET1* program cards.

Another program called *ECAP* (Electronic Circuit Analysis Program), was developed by *IBM* and written in Fortran for *IBM* machines. The designer develops an equivalent circuit of the circuit he wishes to study, based on any model he chooses for the active components. The solution is obtained by matrix methods; every circuit is made up of basic network branches and each branch contains a passive element, a voltage source and a current source. Cards are punched to tell where the nodes are connected, assumed direction of current flow and values of the three basic elements. The program can perform DC, AC and transient analysis and has options for, sensitivity, standard deviation and worst case analysis.

Programs developed by *RACAL Electronics* include a General Circuit Analysis Program for steady state AC and DC analysis and a number of special purpose programs, which include printed circuit layout, video amplifier design, large signal cascode amplifier design, manipulation of four pole matrices, harmonic analysis, analysis of ladder network filters, roots of polynominals and solutions of sets of simultaneous equations.

THE MYTH OF CHRONOS
A Reinterpretation

G. H. S. Jones
Defence Research Establishment, Suffield

THE elder Gods of Greece were decidedly chthonic in many aspects—one might almost say earthy. The later additions to the Pantheon were pathetically human, no more to be feared than an inspired speaker in the Agora. Both could sway fortune against you, but were themselves amenable to bribery or persuasion. How different was the most ancient of the Gods! The universe itself could not contain him, for Chronos was the master of time itself, or perhaps was Time. Strange that around him should be spun the most incredible of myths, for Chronos could survive only by devouring his own child, over and over again. And Zeus, his child, killed him.

The myth of Chronos has never been a popular one, but has fascinated artists through the millenia, from the exquisite bronze now treasured in Luton Hoo to the fearsome imagery of Goya. Poetic imagery, even myths, contain truth but darkly seen. True, Time devours all his living children, and all that now know wind and rain and the majestic wheeling of the universe will in time know nothing, in this universe. But the myth of Chronos transcends the petty truths of man, though man named him Lord of all, devourer of the universe and of his own children. The truth lay deeper than the poet knew. The truth of Chronos, even as the Greeks proclaimed, lay in Time itself.

For time is a little thing, to be measured by man and turned to mundane ends. How small a thing is time! The fleeting second encompasses a world, and how long a time is the instant of death itself? When is now? The whole edifice of science is based upon the measurement of time, and it stands indeed upon the head of a pin, with ample room left for the hordes of angels to dance around it. Yes, how *small* a thing is time? We cannot detect time itself, only the passage of time. When we detect that there has been a change in the universe, we say that time has passed. True, the time arrow points in the direction of increasing entropy, and entropy is measured by change. In the void, there is neither mass, nor energy, nor temperature, nor time itself perhaps? We can detect time only as a change in the physical universe. It may exist beyond that, in some way which can have no meaning to us. We are only enquiring into the meaning of time to some intelligence related in some meaningful way to the physical universe. If the most refined intelligence cannot detect a change in the universe, no time has passed. We may sweep away the technologies, for we are not discussing the measurement of time by man himself, but by some intelligence which is aware of the universe. For such an intelligence, if change in the physical universe is not continuous, time itself is not continuous. If there is a smallest detectable change, there is a smallest detectable time, and time is no longer a steady continuum from everlasting to everlasting. Who but the oldest of the Gods can name this elementary particle of time, what name save Chronon is acceptable?

Let us conceive of the universe as it exists, and let us assume that in our conception, only one

item changes. We need not enquire what this item may be—in present terms it could be a single highly localized photon, or the smallest change in the smallest of elementary particles, it does not matter to us. Let us ask Chronos himself to detect this change, and say that time has changed, or passed. Surely, if intelligence has any meaning at all, it is involved with information. An intelligence without information is meaningless in so far as words have meaning at all. So this detection of the passage of time involves the acquisition of information on the change. In our physical universe, this acquisition of information invariably requires that a signal passes, that radiation of some kind is used as a probe to detect the change. We need not enquire what radiation in the ultimate, but we do know that as the radiation changes, so the available information changes. If we speak in terms of e.m. radiation—which is not necessary—we may illustrate that as we try to reduce the element of change to a minimum, we must increase the inherent energy of the probing beam. If you like to look at it in terms of wavelength, we say that we must reduce the wavelength in order to increase the resolution.

Now in our present search we are looking for the smallest possible change, or the smallest possible interval of time. As we probe smaller and smaller, the macroscopic world continually recedes. So as we spiral downwards to minimum time and minimum change, the universe itself thins out and passes beyond the limits of our ken. The universe is only detectable through change, and if we reduce our change to zero, the universe becomes entirely undetectable. If there is a time interval so small that no change has occurred, we cannot say that time has passed. A static universe cannot exist in any meaning that we can apply to the word. It is a simple tautology, for to exist means to exist *in time*, and time has no meaning to an observer who cannot detect change. For the universe to exist in any way that can have meaning to an observer, it must change. Thus for a void to evolve into a universe, change is required as well as mass and energy. Thus from the simplest considerations we derive a statement which contains Einstein's equation, and adds to it ! Einstein in his most celebrated equation related Mass and Energy through a Velocity, stating that Mass and Energy are equivalent. Though Velocity itself implies time, we may say without recourse to Einstein that according to our reasoning Mass, Energy *and Time* are interchangeable, with some constants of proportionality. Time has Mass, Energy has Time, Mass has Energy and so on. This goes further than Einstein, but no further than the poet who cried "death and decay in all around I see". He was making a simple, and fundamental scientific statement.

Destroy mass, and observe energy, say our nuclear scientists, and prove it with a Nagasaki. Can one perhaps destroy Mass-energy and create . . . Time ? The equivalence constant may be enormous, and perhaps one must destroy a universe in order to create a Chronon. But if chronons exist, *that is exactly what is happening.* The universe only exists, to any observer, when it changes. When it does not change, it does not exist. Time only exists when a change in the universe is detected. The universe and time are created and destroyed alternately, in a succession which produces the awareness of existence in an intelligence. Cogito, ergo sum, is incorrect. I do not think, because I am; I think, because I was. We have a phaseshift ! Time and the universe do not exist together. In time, we detect a universe that existed before us, and when we detect a new universe we are in a new time.

And so Chronos devours his children, destroying his child to create himself. Intelligence exists in time, but bodies exist in the mass-energy universe —sequentially. Perhaps, man has a soul after all, and one which is inherently undetectable, for it exists in time itself. Only the gross body exists in the observable universe. We always see

> *. . . a new heaven and a new earth, for the old heaven and the old earth have passed away . . .*

DF PLOTTING

A. D. V. Ridlington, R.N.S.S.
Government Communication Headquarters

Fixing the position of a distant ship by radio direction finding (RDF) may be considered as the conducting of an experiment. The process of experiment can be divided into three stages:

(1) Asking a question.
(2) Collecting relevant data.
(3) Analysing the data to answer the question.

In the case of RDF position fixing, the simplest formulation of the three stages is:

(1) Question. What is the ship's position?
(2) Data. RDF bearings on the ship's transmitter.
(3) Analysis. DF plotting.

The present paper is not concerned with the scientific and engineering problems of taking bearings, but with stage (3), the problem of extracting the maximum of useful information from the bearings once obtained. Rather than following up the many ingenious geometrical ideas that have been developed in the past, we return to first principles and work out a solution which is perhaps brute-force rather than elegant, but still the brute-force aspects are sufficiently within bounds to be handled by computer. The end-product is pictorial and hopefully easy to understand.

The approach is in terms of probability distributions and is based on Bayes' theorem, following particularly the exposition of I. J. Good and P. M. Woodward[1, 2]. Virtually the same approach to DF plotting has been suggested by P. G. Redgment (unpublished).

We start with the a priori knowledge of the ship's possible locations, before any bearings are taken. The bearings provide new information which we combine with the a priori information to produce the a posteriori knowledge of position—the best that can be done with the information available.

A Priori Information

What is the a priori information and how should it be expressed? The ship is somewhere on the earth's surface so the probability distribution of its position is of the form p (ϕ, θ) where ϕ and θ are latitude and longitude. The probability that the ship is in a small area A centred on ϕ_1, θ_1 is

A p (ϕ_1, θ_1)

and of course the total probability integrated over the earth's surface is 1.

Now p (ϕ, θ) should describe our state of knowledge about the ship's position before any bearings are taken. This will vary greatly from one occasion to another. Typical states of knowledge, listed in order of increasing precision, are

(a) Uniform distribution over the earth's surface. p=constant everywhere, independent of ϕ and θ.
(b) As (a), but p=o everywhere on land.
(c) As (a) and (b), but p=o beyond a certain range from each RDF station estimated as the maximum for propagation of the radio signals received.
(d) As (a), (b) and (c) but p=0 beyond a certain range from a position at which the ship was recently sighted.

The analysis has been developed in such a way that in principle any a priori distribution could be fed in but in practice only the simplest—a uniform distribution—has so far been used. It will be seen however that the final product allows the effect of any different distribution to be assessed quite easily. The initial development has also been simplified by considering a flat surface with a rectangular boundary in place of the earth's spherical, limited but unbounded surface. Not only does this simplify the calculations, it also makes for easier presentation on a flat rectangular computer print-out. The program has since been re-cast for a spherical surface which brings it much nearer to practical evaluation and use, but this change in geometry does not appear to show any important new points of principle.

We start then with the simplest possible distribution, a constant value of p over a rectangular area with p=o everywhere outside.

Single Bearing Information

Next we come to the evidence supplied by the first bearing. What does it tell us about the ship's position? RDF bearings are known to be often inaccurate, so that it would be wrong to say that the position must lie on the bearing line.

The probability of various magnitudes of error, *i.e.* the error distribution function, can usually be obtained from the RDF station's records of past performance. (Note: the existence of suitable records depends upon obtaining true positions or bearings to compare with observed RDF bearings. This can fairly often be done if some systematic check operations are carried out as part of the station's routine). A hypothetical error distribution is shown in Fig. 1. The three main features are:

1. A peak centred on zero error, resembling a normal distribution.
2. A plinth on which the peak stands. It may be level as shown or slope down with increasing error. The highly inaccurate bearings which form the plinth are "wild" bearings, common causes being misidentification, propagation anomalies and human error.
3. A backlobe, due to occasional incorrect resolution of the 180° ambiguity which is a common feature of RDF work.

For initial development the model has been restricted to features 1 and 2, a normal distribution on a flat plinth. The standard deviation of the normal distribution and the wild bearing rate, which determines the plinth height, are specifiable parameters.

Combination of Distributions

Given the a priori distribution, the bearing and the probability distribution of the bearing error, the next step is to combine them. This brings us to the fundamental theoretical proposition on which the analysis is based. It is convenient to express it in the following notation:

x represents the ships' position.

p (x) is the prior probability function of x, *i.e.* it gives the probability of the ships' presence as a function of position in the area under consideration. This is the a priori function p (θ, ϕ) we have assumed.

y represents the new information to be incorporated, in this case the RDF bearing.

p (x/y) is the posterior probability function of x, *i.e.* it gives the probability of the ship's presence at each position knowing that the bearing y has been obtained. p (x/y) is the quantity we want to calculate.

p (y/x) is the probability function of y given x, *i.e.* for each possible position x of the ship it gives the probability that the bearing y would have been obtained. Fig. 1 is an example of a distribution from which p (y/x) can be found by measuring the angle between the bearing of an assumed position x and the observed RDF bearing y.

The relation between these quantities is

$$p\ (x/y) = kp\ (x)\ p\ (y/x) \quad \ldots (1)$$

where k is a normalising constant. Taking logarithms simplifies the handling, replacing multiplication by addition.

$$\text{Log}\ p\ (x/y) = \log p\ (x) + \log p\ (y/x) + \log k \quad \ldots (2)$$

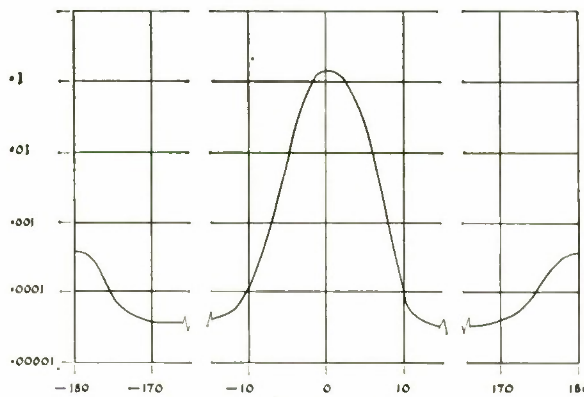


FIG. 1. A hypothetical error distribution.

It is convenient to take logarithms to base 10 and to refer to the logarithms of probabilities as scores. It is tempting to use bels and decibels as units of score, but since the ratios are of probabilities not power it would be misleading. For want of a recognized name, the local term "deciban" is used. If position A has a score 1 deciban higher than position B, then it is 1·26 times as probable, and 10 decibans corresponds to a 10-fold increase in probability.

Incorporating the bearing information now becomes a simple process. Start with a chart of the area showing the a priori distribution which in the simplest case is a constant value of log p (x) at every point. Superimpose a second chart showing the scores log p (y/x). Now add the scores at each point to give the a posteriori score, log p (x/y), according to equation (2) above.

A typical single-bearing "chart" is shown in Fig. 2, with the RDF station itself a short distance off the chart to the west. If normalized the scores would all be negative: to improve the presentation an arbitrary constant has been added to bring the lowest value up to 0. The pattern resembles a searchlight beam, with the highest score along the centreline, falling off on either side gently at first then more steeply until the beam fairs into the base level (the plinth of Fig. 1). Unlike a searchlight beam however there is no

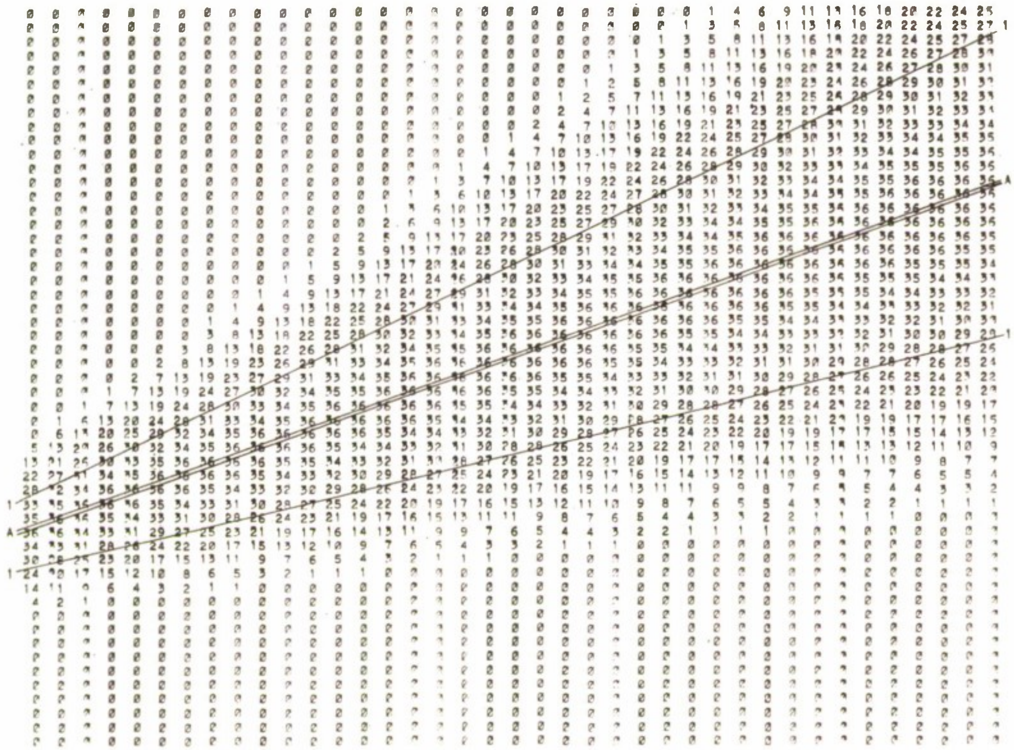


FIG. 2.
A typical single bearing chart.

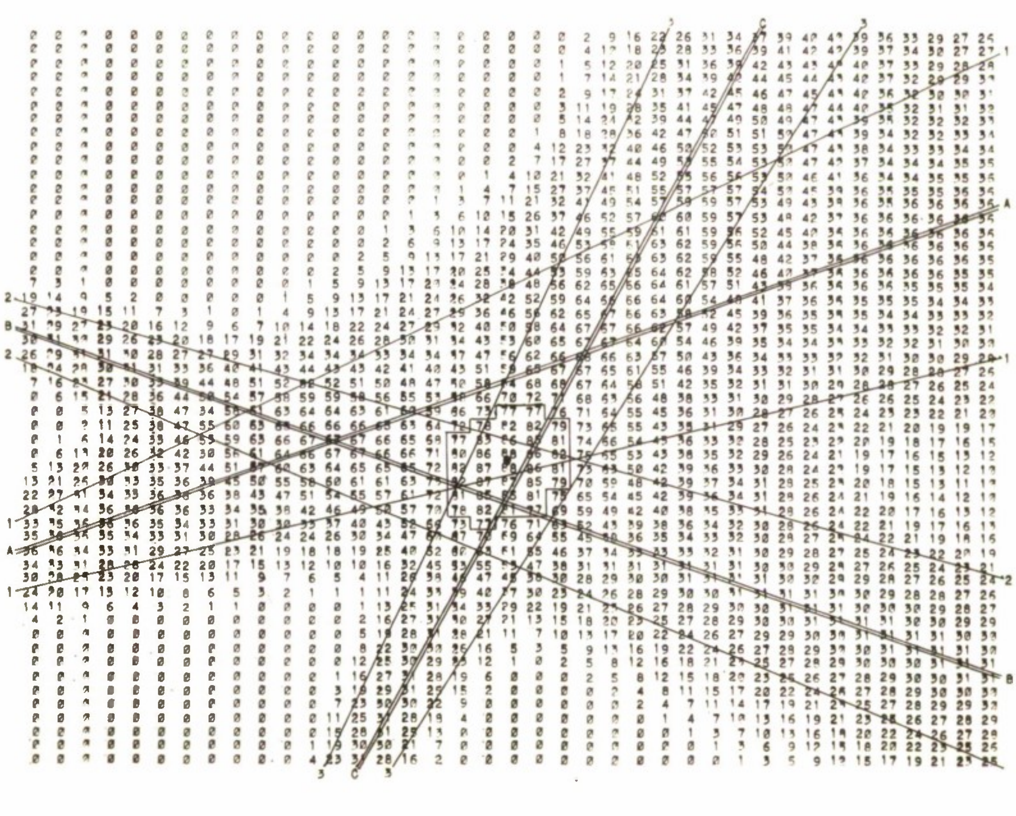


FIG. 3.
A typical 3 bearing fix.

fading with distance as the beam widens: the probability density is a function of angle only. The score falls off by 8·7 decibans at $\pm 2\sigma$ from the beam centreline (the centreline and $\pm 2\sigma$ lines have been drawn in on Fig. 2). The wild bearing rate is 1% which gives an off-beam probability of about $2{\cdot}8 \times 10^{-5}$ per degree, while in the centre of the beam the probability is about $1{\cdot}33 \times 10^{-1}$, per degree, σ being 3°. The ratio is $4{\cdot}75 \times 10^{3}$, equivalent to 36·7 decibans.

Multiple Bearings

Having incorporated one bearing, the others can be dealt with in the same way by adding their score distributions one by one to the chart. This is equivalent to expanding equation (2) to read

$$\text{Log } p(x/y_1, y_2, \ldots y_n) = \log p(x) + \log p(y_1/x) + \log p(y_2/x) + \ldots$$
$$\ldots + \log p(y_n/x) + \log k \qquad \ldots (3)$$

In doing this we are assuming that the bearing errors are independent of one another, a somewhat questionable assumption which is accepted for two main reasons

(a) that it is very difficult to allow for non-independence
(b) that other methods of DF plotting generally make the same assumption and do not appear to give very misleading results as a consequence.

An example is shown in Fig. 3 of a 3-bearing fix, with two bearings from stations having $\sigma=2°$ and wild bearing rates of 5% added to the original single bearing of Fig. 2. Here again the stations are off the chart: this is done to give maximum detail, within the confines of a computer printout, to the region of greatest interest for position-fixing.

Presentation of Results

In a sense the solution is now complete. All the information relevant to deciding the ship's position has been incorporated in the picture: non-bearing information in the a priori distribution and bearing information subsequently. However the final distribution chart suffers from the defect of being too comprehensive and detailed for most purposes. To provide a more practical and usable answer we want to extract certain salient features. What are the most useful features? The first is the most probable position of the ship or best point estimate (BPE). This is easily found within the computer program as the location with the highest score—marked with a spot in Fig. 3. But the BPE is unsatisfactory as an answer without supplementary information. With a flat maximum or multiple maxima there may be regions far from it which are nearly as probable as locations for the ship; on the other hand the maximum may be very sharp so that the ship is unlikely to be anywhere but very near to the BPE. What is needed is an indication of the extent of the high-probability region. Several choices are available. The area can be defined for example as the smallest region containing some proportion, say 90%, of the total probability, or as the region within a contour some fixed level such as 10 decibans below that of the maximum. In Fig. 3 the region containing 90% of the total probability has been outlined: the contour is at approximately 77 deciban level as determined by numerical integration of probabilities.

Discussion of a Priori Information

This exposition has used a number of simplifying assumptions and skated over various difficulties in order to complete the main story without too much side-tracking. It is now time to go back over the tracks and consider some of the important side-issues, starting with the a priori distribution. It is perhaps worth observing that the incorporation of new information by the process of equation (2) or (3) does not have to follow any particular order. The final score distribution is the sum of a number of individual distributions, each representing the information provided by one piece of evidence or another. The so-called a priori distribution could just as well be added in last instead of first. It might be better to think of it as the distribution resulting from all the non-bearing information available: if it consists of several independent items it can be formed by adding the individual distributions due to each.

Let us return to the implications of choosing a uniform a priori distribution. The choice is one which would naturally be made by someone who says that he wants to assume no knowledge of position apart from what the bearings will tell him. But it can be replied that choosing a uniform distribution is not assuming no knowledge; on the contrary it implies knowledge or expectation that the probability of the ship's being at A is equal to the probability of it's being at B. Indeed whatever distribution the would-be ignorant chooses, he can be accused of implied knowledge. This dilemma has exercised greater pens than mine and is unlikely to be resolved here and now. The line of escape which seems most rational to me is: while one disclaims particular knowledge about ships on the globe, there is a more general knowledge of the behaviour of the natural world, inculcated by experience in all of us, that a uniform distribution is a good initial assumption in a new field where nothing specific is yet known. It is rational to use this general experience when there is no specific knowledge to guide us, or when we choose to ignore our specific knowledge for the time being.

If we start with a uniform distribution, it seems very sensible to modify it to take account of the

fact that ships do not go on land. Should we make $p=o$ on land ? This is a more drastic step than might appear, since it makes the score$=\log p = -\infty$. What happens if there is some mis-identification and the RDF stations take bearings on a land transmitter thinking it to be a ship ? However good the bearings, the final score will still be $-\infty$ everywhere on land and the BPE will be placed somewhere at sea. This is more misleading than locating the "ship" on land and stimulating the RDF controller to consider the possibility of mis-identity. We can get something much more satisfactory by estimating how often mis-identification occurs, say once in 200 occasions, and making $p=0{\cdot}995$ at sea and $p=0{\cdot}005$ (score down by 23 decibans) on land. If the bearing information is rather weak and gives some fairly high scores on land as well as at sea, the a priori distribution will force it out to sea where it almost always belongs. But if there is a strong consensus among the bearings that the transmitter really is on land, their evidence will more than outweigh the 23 deciban a priori factor against this conclusion.

Bearing Error Distribution

It is an advantage of the present method that the bearing error distributions used in plotting can be modelled closely on experience, the limits being set only by convenience and the availability of performance records. It is not necessary to assume a distribution described by some analytic function in order to make calculation feasible. The common use of a normal distribution in RDF analysis has in fact drastic misleading effects more than a few σ away from the central peak. For example, if we use a normal distribution with $\sigma=3°$ and happen to have a wild bearing 30° off target, the score assigned to the true position on account of the bearing will be 217 decibans down on the value for a correct bearing, with a slope of 14·5 decibans per degree. The result is that the wild bearing pulls the BPE some distance towards itself and away from the spot that the other bearings would indicate if left to themselves. If however the bearing error distribution is allowed a comparatively level plinth some 30 or 40 decibans down, a wild bearing will have little effect on the BPE indicated by the other bearings provided that they give a reasonably sharp fix between themselves. In effect one is saying that bearings more than five or six standard deviations off target give little information about the true position and so are allowed to have little effect on the a posteriori probability distribution in that region.

The implications of bearing scores being independent of range may need some explanation. If we assumed an infinite earth with no propagation limit, there would be no range restriction on transmitters heard by the RDF station. Normalizing the probabilities would result in scores of $-\infty$ at all points, *i.e.* the probability tending to zero everywhere. This extreme result is the natural consequence of the extreme assumptions, a finite but not necessarily constant density of transmitters extending over an infinite area. In the real case we are limited by the finite area of the earth, and usually further limited in range by propagation conditions. This keeps the probabilities above zero.

If on the spherical earth we combine a uniform a priori distribution with the evidence from a single bearing, as in Fig. 2, the scores along any radial line in the main beam do not fall as the distance from the RDF station increases, despite the broadening of the beam. Thus the total probability that the ship is located within the main beam at a range of $r \pm \delta$ miles is proportional to r. This reflects the fact that near the station the beam is very narrow and covers only a small area of sea, so that the a priori probability of the ship's being in this area is correspondingly small.

Conclusions

The method aims to give a complete answer to the question: what can be said about the ship's position on the evidence available ? Given this complete answer in the form of a probability distribution, key features such as the most probable location and the region of high probability can be defined and extracted as output. Although the accent is on RDF bearings, any item of evidence relating to the ship's position can be incorporated provided it can be expressed as a probability distribution independent of the other items. There is no need to limit the representation of distributions to certain analytic functions, such as the normal distribution, in order to make the problem soluble. The results, and the way in which they follow from the input assumptions, are readily describable step by step in terms of probability theory, and can be straightforwardly displayed on a chart.

The big handicap is the brute force nature of the approach, which in its primitive form would involve calculating probabilities for every intersection on a fine grid covering the earth though of course one can do much better by starting with a coarse grid over a wide area to locate the high probability region, then using a finer grid to cover this smaller area. The method is not fully developed and does not compete, at least at present, with established methods. The crucial question is whether the program efficiency can be improved to give operationally acceptable results without requiring too much computer time.

References

(1) Probability and the weighing of evidence. I. J. Good. Charles Griffin, 1950.
(2) Probability and information theory, with application to radar. P. M. Woodward. Pergamon Press, 1953.

PROBABILITY, JUDGMENT AND MIND
2—The Nature Of Mind (Part I)

K. W. Harrison, R.N.S.S.
Admiralty Surface Weapons Establishment

The Psychic Universe

"Those who refuse to go beyond fact rarely get as far as fact; anyone who has studied the history of science knows that almost every step has been made by the invention of a hypothesis which, though verifiable, often had little foundation to start with."—T. H. Huxley.

In the first paper of this series[1] we proposed adding a "suggestion" to the technique of probability expounded by Dr. I. J. Good[2]. The "suggestion" was that for scientific research to be at its most fruitful the "Unconscious" should be recognized, specifically, as being of fundamental importance in probability judgments and scientific inference. Good's theory allows for suggestions to be added or rejected at will; the consequence of acceptance being an increase in objectivity. Three further suggestions are advanced in this paper. They are (1) the Unconscious is part of a psychic universe which interpenetrates and interacts with the physical world we know; (2) this universe is similar to the one described by Professor Sir Cyril Burt[3] and to that formulated by Professor Carl Jung[4]; and (3) the modern interpretation of particle physics in terms of mathematical space eliminates the distinction between body and mind, and shows a living organism as one entity which is neither of a purely psychic nature, as conceived by Fechner[5], nor a purely material one, as conceived by Koffka[6], but of the nature of a "transcendent monism" as described by Professor Burt[3].

The findings of current research in particle physics and speculative, but informed, opinions of scientists from a variety of disciplines support these suggestions. Furthermore, they hint that the time is approaching when such opinions may be open to experimental investigation. Illustrations will be given of the picture under development in particle physics of a physical substratum, and of similarities between this and pictures which have been drawn of a psychical substratum. Speculation throughout is rooted in fact—the position is similar to that described by Professor Wheeler of Princeton University, who has said (talking of geometrical space[7]) " . . . nobody is inventing these fluctuations in geometry. The interesting thing is that they are forced on us by the very mathematics that go with general relativity and the quantum principle . . . " Likewise in psychiatry and psychology the conclusions of Freud, Jung, Burt, and others, are based on facts and shrewd observation.

This does not mean that the fields of probability and statistics are forsaken for those of particle physics and psychology—these already overlap. Throughout our discussion many relevancies to subjective probability and statistics will appear; relations between mind and probability and judgment have already been established. Moreover, measures of subjective probability can be interpreted in terms of information theory and entropy[2], and in terms of neural networks[8, 9], thus showing that subjective probability relates to the brain as well as the mind—should the two be different.

There has been much disagreement between learned scientists as to whether the two are different. Professor Boring[10] points out that it is one thing to claim that mind and matter are just alternative aspects of the same Reality; it is another thing to show that this is so. Boring also remarks that, whether or not this can be done, the two often have to be treated differently. Professor Burt argues that, in view of modern physics, the psychic system should be regarded as analagous to a field (consistent with Gestalt psychology) and that we should regard consciousness as an awareness of relations and events rather than of substances and attributes. He claims that a modification of the dualistic approach along these

lines is called for by the evidence we have before us. It will be shown that this evidence throws emphasis on to the thermodynamics of mental (particularly emotional) activity and on to psychological time.

The names of Professor Burt and Professor Sir Charles Sherrington figure prominently in the list of those holding a dualistic outlook. Among the monists, holding opposing views, are Freud and Dr. Grey Walter. The pictures of mind most near to the promised substratum of particle physics appear to be those of Burt and Jung. The philosophy of Jung is acknowledged to be most difficult to comprehend and open to various interpretations. But he could be classified as a dualist for his suggestion that death does not end existence (except for the individual consciousness). The body-mind dichotomy is clearly controversial and it is open to the kinds of conceptual error and bias which were discussed in the previous paper. It is interesting and worthwhile to consider Sherrington and Freud in this respect.

Sherrington was a neuro-physiologist, and Freud spent 15 years as a neuro-physiologist, before the mundane necessity of providing a better living compelled him to go into medicine. Both were first-class scientists; they based their opinions on fact and observation. It would seem that both were biased in their attitude to religion, and this is perhaps reflected in their scientific theorizing. Both were led by their work to admit the existence of unconscious mind—although Sherrington called it subconscious (did this have Freudian significance ?). But they arrived at, and used, their conclusions in different ways. Sherrington's cautious and restrained speculation can be contrasted with Freud's insight, the one cautiously building up to the concept of " subconscious " mind, the other postulating the Unconscious as a first and basic step in a series of steps which led to the astonishing field of psycho-analysis. Sherrington, in fact, is referred to as " wise and cautious " by Dr. Joan Wynn Reeves[(11)], a modern writer on philosophy and psychology, to whom further reference will be made. Freud was a genius, described by Calvin S. Hall[(12)] as one of the few truly " universal " minds like Shakespeare and Leonardo da Vinci.

Freud, perhaps in trying to explain too much, or possibly because of some conceptual bias (he would never submit himself to fellow psychoanalysts for analysis), enunciated principles which were unacceptable to some psychologists of his day, and still are to present-day psychologists and psychiatrists. Jung, a young Zurich psychiatrist, was among the first to become interested in the new ideas of Sigmund Freud. For some years he was an enthusiastic and favoured participant in the infant psychoanalytic movement, but soon serious ideological and personal differences developed which resulted in definite and increasingly embittered cleavage. Jung founded his own school with a distinct name: Analytical Psychology.

Sherrington, perhaps through over-caution, or possibly because of proper scientific restraint, appears reluctant to be drawn into detailed speculation. Even so, the views he gives on Natural Religion and Evolution are open to question. His strength, seemingly, lay in analysis rather than synthesis. Perhaps this is why he chose, and remained in, his field of study. In contra-distinction, Freud was intrigued by problems of the mind: neuro-physiology and medicine were fields too confined for his ranging interests. He was at heart a psychologist and not a psychiatrist.

That opportunities were available to Sherrington for speculative research is evidenced by the case of the pineal gland. In his day this was thought either to be vestigeal or of no functional value—it is known to-day to produce Melatonin, used in hypnosis, and found to affect the nervous system. Also, Sherrington dismissed the chambers of the brain as having no nervous significance, saying that they served only to increase the surface of the brain—we now know that this is *not* the only rôle they play. The dismissal of their significance occurs during his rejection of the views of Galen (a celebrated second century A.D. physician) that the chambers were of fundamental importance in the working of the mind. Judging the brain and nerves to be tenanted by subtle and ultra-tenuous spirits Galen saw in the chambers of the brain their reservoirs. It is strange that Sherrington should reject the claim that they have significance in the working of the mind on the grounds that they have no nervous significance, for Sherrington himself[(13)] distinguishes between mind and brain, admitting that the only correlations to be observed between them are gross ones.

Professor Burt, echoing this duality some eighteen hundred years later, sees a similar occupancy of the brain and certain of the nerves by a psychical mind *and* offers suggestions for the inter-correlation of mind and nerve. He refers to developments in particle physics and remarks how easy it would be for the modern physicist to conceive of two completely separate universes existing simultaneously. The two systems might interpenetrate yet an observer belonging to either would be unaware of the other system.

Jung's philosophy is complementary to that of Sir Cyril Burt. Of all the psycho-analytic schemes it is, perhaps, the most well-rooted in the world outside psychiatry (it could be argued that he has a more representative sample !) and it is also the one most capable of application to the outside world. Jung retains the Freudian term *libido* but

gives it a different meaning. He means by the term a life energy underlying all natural phenomena, including the human psyche—apparently rather similar to a concept of *élan vital*. Although it takes many forms, it can no more be obliterated than the energy of physics, which Jung often uses in analogy. In his later writings these direct analogies to physics give way to a poetic sense of the dark life forces within us, which are also divine-forces which threaten and ennoble us and which may not be denied.

The remainder of this paper will be devoted to the elucidation and expansion of the foregoing concepts, and their interpretation into terms of modern physical thought.

From the time of Plato men have sought to distinguish between material and non-material aspects of living entities and, *vice-versa*, other men have striven to eliminate this distinction. Galen conceived the brain and nerves to be occupied by spirits. Fernel, in the sixteenth century—an outstanding scientific thinker of his time—saw that within the brain certain spirits of the life-principle were sublimated step by step with man's intellect and reason. Sherrington, in turn, retained a division between matter, or energy, and non-matter, but changed the nomenclature from " spirit " to " mind ", or " psyche " He maintained a distinction, also, between various grades of mind. A phenomenon that puzzled Sherrington was that mind seems to come from nothing and to return to nothing. The devolution into nothing was for him as difficult to accept as the evolution out of nothing. To account for this he postulated a joint evolution, within one entity, of body and mind, with only gross correlation between them. In his own words " . . . if the mental were some form of the energy it adheres to, the story would be one of energy transformation ". Sherrington also saw that time was of prime importance in the working of the mind. He pointed out, too, that differences between living and non-living had disappeared; there was no longer any clear cut lower limit to mind. Panpsychism had already developed its theme on this* and L. Ron Hubbard was subsequently to elaborate extensively on it[14]

*Views of this kind seem to attract a wide variety of reactions from contemporary scientists. These range from bitter and scathing condemnation (Grey Walter on L. Ron Hubbard) to sardonic humour (Boring on Fechner). Boring explains reactions of the mid-nineteenth century thus: " For Fechner, in the materialistic age of science, to argue for the mental life of plants, even before Darwin had made the mental life of animals a crucial issue, was for him to court scientific unpopularity." Professor Capek of Carleton College, Minnesota, states that it is certainly unfair to place Leibniz's or Whitehead's panpsychism epistemologically on the same level as pre-Socratic hylozoism or primitive animism.

The period when Sherrington was writing on life and mind was rich in creative, and varied, thought on these subjects. Freud was writing *An Outline of Psycho-Analysis*; Koffka had just published his work on Gestalt psychology; Schrodinger was writing on life in terms of energy and entropy; and C. S. Lewis was writing of entities which were not material[15].

Koffka and Schrodinger introduce us to attempts to unify body and mind—sometimes as one completely psychic entity, other times as a completely material one. These (for our purpose) started around the middle of the nineteenth century, in the earliest days of experimental psychology, with Gustav Fechner. Fechner's contribution to posterity was that he introduced the concept of measurement to psychology. While there is some doubt as to what he actually measured, the importance of his innovation of method is beyond question. Fechner's view of the relation of body and mind was not that of psycho-physical parallelism, but what has been called the " identity hypothesis " and also " panpsychism ". The writing of an equation (the Weber-Fechner law) between the mind and the body in terms of Weber's law seemed to him virtually a demonstration both of their identity and of their fundamental psychic character. Although he began with a dualism it must be remembered that he thought he had shown that the dualism is not real and is made to disappear by the writing of the true equation behind the two terms. The influence of Fechner's introduction of measurement still pervades psychological experimentation.

Another important contribution to psychology was initiated in 1912 by Wertheimer: this was Gestalt psychology. To this day, the patterned character of physical fields provides a useful analogy with patterns of organization of psychological events. Hence modern Gestalt psychology sometimes goes under the name of *field theory* to contrast it with other, more analytical, viewpoints. Koffka in 1935 represented a search for the *material* basic of all *cosmic* phenomena, which would account for all inorganic, bio-physical and mental processes; the last-named category would include civilization and its works. Koffka's definition includes the statement that organization is the process that leads to a Gestalt and that organization is diametrically opposed to chance distribution. This returns the discussion to information theory, entropy and Schrodinger.

Among others of this time (including Freud—for whom psychic energy was no different from bodily energy and was, therefore, limited in quantity) Schrodinger said that perhaps the dichotomy could be breached by the explanation of life in terms of physical laws which were, as then, un-

known. His paper "*Heredity and the Quantum Theory*" was the forerunner of many attempts to portray life in terms of entropy and information theory—the latest of which feature such things as *Biological Entropy Pumps*[16] and *Times Arrow*[17].

Schrodinger saw that living matter, while not eluding the laws of physics as established to date, was likely to involve other laws of physics, as then unknown, which, however, once they were revealed, would form just as integral a part of science as the former. He wrote: "It is by avoiding the rapid decay into the inert state of thermodynamical equilibrium that an organism appears so enigmatic; so much so, that from the earliest times of human thought some special non-physical or supernatural force was claimed to be in operation in the organism, and in some quarters is still claimed."

Sir Arthur Stanley Eddington, the greatest astronomer of his day, wrote: "All through the physical world runs that unknown context, which must surely be the stuff of our consciousness. Here is a hint of aspects deep within the world of physics and yet unattainable by the methods of physics."

Let us compare these views with those of present-day particle physicists. Gerald Feinberg, Professor of Physics at Columbia University[18] offers a modernized version of Schrodinger's statement. He writes: "Some physicists have argued that the laws of quantum mechanics are insufficient to explain living phenomena (Walter Elsasser) or mental phenomena (Eugene Wigner). I think it is premature to draw these conclusions, since the detailed study of living phenomena with the full use of physics and chemistry is rather recent, and its spectacular progress is such that predictions of impotence may soon be falsified."

Likewise, R. Bernhard[19] presents a modern version of Eddington's comment: "The only permanent elements of nature are not particles but certain of their abstract attributes lying concealed in the transcendental symmetries of fictitious mathematical spaces. The Harmony in nature is now seen in particle theory as synonymous with abstruse symmetries incalculably more sophisticated than the obvious geometrical patterns trapped by the 'Real' space at the time of man's apperceptions". That Eddington's "stuff of consciousness" is one aspect of this "Harmony in nature" is the theme of this paper.

Returning to entropy, Schrodinger contrasted the purely mechanical with the thermodynamical conduct of a living organism. He observed that Life seems to be orderly and lawful behaviour of matter, not based exclusively on its tendency to go over from order to disorder, but based partly on existing order that is kept up. In his paper he sketches the bearing of the entropy principle on the large-scale behaviour of the living organism. The relationship between a living organism and its environment is expressed in terms of statistical theory. This involves a change of sign in Boltzman's equation to give

$$-(\text{entropy})=k \log ({}^{1}/_{D})$$

where k is Boltzman's constant and, as D is a measure of disorder, ${}^{1}/_{D}$ is a direct measure of order. D is a quantitative measure of the atomistic disorder of the body in question. The disorder it indicates is partly that of heat motion, partly that which consists in different kinds of atoms and molecules being mixed at random, instead of being neatly separated.

We have previously described (Reference [20]) how the equation

$$-F(x)=k \log (\text{odds})$$

is derived from the logistic curve. In this transformation, unless there is a change of sign in F(x), the discussion is changed from one concerning the occurrence of events to one concerning their non-occurrence. This seems consistent with Schrodinger's observation on existing order being kept up. It is of incidental interest that the word 'entropy' was coined in thermodynamics to mean transformation.

At this point we must refer again to the Weber-Feckner law. This is of the form

$$S=k \log ({}^{R}/r), \text{ or } S=k \log(R')$$

where r is the threshold value of stimulus R, R′ is the stimulus in terms of r, and S was claimed to be sensation. This was based on certain assumptions concerning "just noticeable differences" of sensation and it raised much controversy. Fechner assumed that every liminal increment of sensation equals every other one. He also based his work on the normal law—it was easier then to assume that the normal law is a law of nature. In fact the "jnd's." are not always equal, and we have seen that in many cases—particularly at the tails of the distributions—the logistic is preferable to the normal curve[21]. This raises the interesting point that it has been shown that Weber's law is apt to be wrong for the low values of any convenient measure of stimulus intensity. Another suggestive feature is that the psychology which depends on this law also requires the existence of ***negative sensations***—the full significance of this will become manifest in the section of the paper which follows. Fechner believed that "the representation of unconscious physical values by negative magnitude is a fundamental point for psychophysics"[5], and it was by way of this mathematical logic that he came to the doctrine of the unconscious. It is hardly necessary to point out the similarities between the three equations we have just considered, or the terms composing them.

Dr. I. J. Good calls log (odds) the plausibility and differences between plausibilities he calls the weight of evidence. In *Probability and the Weighing of Evidence*[2] he points out that the same units can be used for measuring weights of evidence and entropy. Shannon demonstrated that the change in the function defined by

$$S_I = -k \sum_i P_i \log P_i$$

measures the amount of information in any message and it has been shown that the entropy of Clausius, who coined the word, is derivable from that of Shannon. Dr. Good remarks that his (Good's) distinction between an "experiment" and an "event" has made it possible to introduce entropy in a rather more direct manner than that used by Shannon, who is not concerned with amounts of information relative to alternative hypotheses. But if such amounts of information are considered, it is found that, *apart from sign*, they form a set of relative weights of evidence. Entropy may be said to measure the state of ignorance of a person relative to a well-defined question, if the person only knows a probability distribution. It measures the expected number of questions he will have to ask in order to go from his state of partial knowledge to a state in which he knows everything about the well-defined question. We could consider a physical system and ask the question "In what quantum state is this system?" Of course one can never say in which state a system resides but rather can only give a probability for the system being in a particular state. The probability distribution for the states must be consistent with the observer's knowledge.

An amusing but cautionary jingle[22] against the indiscriminate use of information concepts in psychology goes as follows:—

Shannon and Weiner and I
Have found it confusing to try
To measure sagacity
And channel capacity
By Σ Pi log P_i.

In addition to the foregoing equations with their accompanying changes of sign, we have already seen[21] several cases of similar sign changes in particle physics. These accompanied changes from conduction of electricity to the conduction of heat and from the mathematics of the denumerably infinite to the mathematics of the non-denumerable, or the transfinite, and were introduced by the use of the logistic function. It is worthy of note that a transfer from finite to transfinite can be shown, theoretically, to follow the operation, or process, of eliminating the quantization of matter[21], and, also, that Schrodinger[23] was forced to admit that he no longer believed that quantum jumps really occur. He suggested that they are better explained by so-called resonant properties of the atom. Taken together this plexus of processes is in agreement with Professor Burt's concepts and with the current view of matter as attributes of transcendental mathematical spaces. It also provides a rationale for investigating the thermodynamics of mental activity.

With regard to Bernard's "fictitious" mathematical spaces, to the transfinite series and our opening quotation, it should be recorded that John Campbell[21] has suggested that the limit of the transfinite series is the limit of the imagination. Appropriately, Professor Capek has written[24] "... to-day it is obvious that the objective substrate of physical phenomena cannot be described in imaginative terms; all sensory qualities are basically on the same phenomenal level, which is a result of interaction of our conscious organism and the transphenomenal physical processes. The transphenomenal level itself seems to be thus forever inaccessible both to our perception and to our imagination; it can be neither perceived nor imagined. Abstract mathematical constructs seem to be to-day the only way, not to reach, but to *represent* the structure of the transphenomenal plane". In connection with the last sentence, Bethe has remarked that to tackle the problem of the nucleus more powerful mathematical tools are needed. In response to this Gunther and Campbell[21] have suggested Cantor's transfinite sets. In this respect we can point out that we have already demonstrated[21] several applications of the logistic function in particle physics which involve transfinite numbers.

Cantor's original work[25] contains interesting material relevant to our discussion. In it are quoted his opinions that:—

(a) functions of transfinite numbers are expressions of processes and relations in the outer world (as distinguished from the intellect):
(b) the process followed in the correct formation of a concept (which is everywhere the same) involves first the "existence" of the concept (pure maths.) and then proof of its existence by applied mathematics (metaphysics)—the latter process coming under the heading of psychology:
(c) in that they are "actual" these concepts modify, in a definite way, the substance of the mind:
(d) the reality of our conceptions implies the reality of the "external" processes because, according to Cantor, this is a consequence of the "unity of the All, to which we ourselves belong".

We can add to these the observation that considering, also, that aggregates play a vital part in

his work it is not surprising that in this study we have arrived at the realm of the transfinite by our use of the logistic. What remarkable intellectual powers and prescience Cantor possessed! Consider his views not only with regard to the processes we have just discussed but with regard to the speculations of Good, Russell, and Uttley[8].

Good conjectures that when we estimate a probability intuitively, our nervous system contains some simple approximate physical embodiment, *i.e.* representation, of the probability. He quotes Russell and Uttley who suggest a time delay which would make conditional probabilities easily embodiable. Good extends the conjecture and shows how the plausibility of a hypothesis could be embodied to obtain a conceivable explanation of why we often have a rough immediate intuitive appreciation of odds, information, weight of evidence, and tendency to cause. In another part of his paper he refers to probabilistic causality and indicates that the notion of weight of evidence has application to several philosophical problems. We have already made reference to Bayes's Postulate[21] using the logistic curve plotted in terms of plausibility; and using the idea of the transfinite (to which we were led by the logistic) we have been re-introduced to Bayes's Postulate. We have, in fact, seen enough in our applications of the logistic[21, 26] to endorse Good's opinion that the technical, philosophical and practical aspects of a subject are of roughly equal interest. Another, potential, use for the logistic with respect to neural networks is seen in a paper on "Error Minimizing Neuronal Nets" delivered by L. A. M. Verbeck at a symposium on Self-organization[8] where the logistic function would represent the probability distributions in Figs. 2 and 3. This is to be expected not only because of the association of the logistic with the representation of aggregates, but also because of its association with subjective probability.

While on the topic of neural networks it should not be left unnoticed that Freud made a contribution to science in this context. For some time Freud sought to relate his discoveries to neurophysiological activities within the brain but here success eluded him, and eludes us still. However, he was able to point to a relationship between the associative method of recall and the network of nerve filaments and electrical circuits within the brain on which this must depend and which provide innumerable links between one idea and another. Much of this had been known and studied for many years before his time, but once again it was his particular contribution to point out the vitally important rôle played by emotion in determining whether or not a chain of associations would in fact be readily followed, and could lead automatically to a particular idea or constellation of ideas appearing in consciousness. Hence we see a physiological relation between Emotion and Judgment.

Sherrington cited the extreme rapidity of mental changes of ideas and of moods as evidence of the difference between mind and brain. He wrote: "The mind is a something with such manifold variety, such fleeting changes, such countless nuances, such wealth of combination, such heights and depths of mood, such sweeps of passion, such vistas of imagination, that the bald submission of some electrical potentials recognizable in nerve centres as correlative to all these may seem to the special student of mind almost derisory."

Professor Feinberg cites a similar ephemerality of particles as manifestations of an underlying structure to physics. He points out that one of the most striking characteristics of particles is that at high energies they are easily created or destroyed or transformed into one another. It seems strange that this would occur if particles were really fundamental. Professor Burt anticipates the union of the two views: "The ultimate truth can only be that *both* worlds as we know them—the physical and the psychical—are but working models of a deeper and fuller reality, at present unknown, and possibly unknowable. It is tempting to suppose that it must be in some way psycho-physical, and therefore 'neutral' in the sense that it is neither *purely* mental nor *purely* material. In that case, it might be said, we are after all opting for a kind of 'neutral monism'. But it would be a transcendent not an immanent monism".

Sherrington continued, "It is, further, more than mere lack of corresponding complexity which frustrates the comparison (between mind and brain). The mental is not examinable as a form of energy. That in brief is the gap which parts Psychiatry and Physiology. No mere running round the cycle of the 'forms of energy' takes us across that chasm. Perhaps that is what William McDougall was meaning when he exclaimed, 'Medicine has nothing to learn from psychology nor psychology from medicine'".

The answer to the question of the relationship between the working of the brain and the working of the mind Sherrington surmized to be: "thoughts, feelings, and so on are not amenable to the energy (matter) concept. They lie outside it. Therefore they lie outside Natural Science . . . As followers of Natural Science we know nothing of any relation between thoughts and the brain, except as a gross correlation in time and space" He then proceeds to outline how, in some ways, this is embarrassing for biology, pointing out that the categories of living and lifeless as regards science disappear; there is no radical scientific difference

between living and dead. "Time was when to think and breathe were on an equality as attributes of Life. Now living, so far as breathing, moving, assimilating, growing, reproducing, *etc.*, amount to life, has by natural science been accounted for—some might say 'explained'. There is nothing in them which does not fall within the province of science—they are chemistry and physics. But though living is analyzable and describable by Natural Science, that associate of living, thought, escapes and remains refractory to Natural Science."

The significance of the plexus of processes and changes of sign (*or direction*), to which we referred earlier, was enhanced by the analogies between neural networks and "subjectiveness" (in the statistical sense). In the following section further significance will be gained when this plexus is related to observations on *Times Arrow*, Mathematical Spaces and certain physiological phenomena. Not only are these factual; they suggest possibilities of experimental investigation—with the inference that perhaps the mental may after all be examinable as a form of energy.

It is to Sherrington's credit that he foresaw the analogy between the brain and a computer. He wrote, ". . . of three aspects of mind broadly distinguishable, the effective, connotive, and cognitive, one inference perhaps to be drawn from the human brain is that growth of cognitive processes makes wholesale demand on numbers of nerve-cells. We can understand how this might be if a principle such as the 'association' of old-time psychology be largely engaged in it. An automatic card-index on an enormous scale with copious cross-references may be asked for. This part of the brain is evidently cumulative in time. And so is knowledge. May it not be that there is a correlation between the two? . . . "

Professor Burt, the latest in the succession of dualists, and possibly one of the last, points accurately to the solution to the mind/body relationship and at the same time incorporates the best features of many philosophies into his theme, such as the Gestalt "field" and the concept of "information", as well as the findings of modern physics. He describes as manifestly false a recent declaration that there is nothing in the life or behaviour of man which cannot ultimately be explained in terms of the chemistry of the nervous system. In his speculative paper on "Mind and Consciousness" he replies to this assertion thus: "When an electric impulse stimulates the nerve-cells at the back of the brain, I see colours; when an impulse of precisely the same type stimulates the nerve-cells of my temporal lobes, I hear musical sounds. And these conscious experiences and their differences cannot themselves be described in terms of the chemical changes in any kind of matter. The phenomena and the laws of chemistry have nothing to do with seeing green or red, or hearing a symphony concert. If the brain was really responsible for such characteristics or could generate such experiences, then it would be much more like what is popularly termed a mind, and quite different from the pinkish putty-like mass dissected by the anatomist or stimulated by the surgeon's electrode on the operating table."

The difficulties in comprehension arise, according to Professor Burt, because of tacit assumptions that the phenomena in question are to be described in terms of substances and their attributes, that is, in terms of the traditional logic of subject and predicate. Modern logic, however, insists on the supreme importance of a third category, namely the category of relation; and modern science is built up by arguments which consist of relational propositions rather than of predicative propositions.

Dr. Joan Wynn Reeves describes, admirably, these changes in logic, together with their accompanying changes in assumptions and outlook in philosophy and psychology in "Body and Mind in Western Thought"[11]. Professor Capek also refers to the inadequacies of the traditional logic in the following quotation which is worth giving in full, for its clear summing up of the situation, for its reference to temporal span, and for its wealth of references.

"At that time it was not sufficiently clear that the substance-attribute relation reflected too slavishly the linguistic noun-adjective relation; it had been uncritically assumed that grammatical structure is a true replica of the structure of reality. Only under the impact of James, Ward, and the Gestalt psychology were the fictitious substantial psychical atoms dissolved into the dynamic wholeness of the stream of thought. Although in physics the concept of substance seemed to be fairly well established at the turn of the century, it eventually yielded to the growing pressure of the recently discovered facts. The substantial aether as well as substantial material particles are being replaced by events. In Jeans's words:

> 'Thus the events must be treated as the fundamental objective constituents, and we must no longer think of the universe as consisting of solid pieces of matter which persist in time, and move about in space . . . Events and not particles constitute the true objective reality . . . '.

The same conclusion is reached by such widely different thinkers as Russell, Jeans, Whitehead, Bergson, and Bachelard. A few lines after the

passage just quoted Jeans quotes Russell approvingly:—

> 'The events that happen in our minds are part of the course of nature, and we do not know that the events which happen elsewhere are of a totally different kind.'

Evidently there is growing realization not only that the category of substance should be superseded by that of process, but also that process is a category applicable to both physical and mental realms. Bertrand Russell's words indicate not only that the traditional substantialism is dead both in physics and psychology but also that the Cartesian distinction between the mental and physical must be given up, because in either realm the concept of event becomes fundamental. This does not mean that the distinction between the two realms is completely wiped out. Although both 'matter' and 'mind' are constituted by events, the differences between 'physical' and 'psychological' events remain. One most conspicuous difference has already been mentioned: *the difference of temporal span*. Perhaps along this line the true solution of the traditional mind-body problem should be looked for, and Bergson's 'Matter and Memory' represents an interesting attempt in this direction ".

Professor Burt sees the " stuff of consciousness " of Eddington as a psychic universe consisting of events or entities linked by psychic interactions, and obeying laws of their own. This interpenetrates the physical universe and partly overlaps it, much as the various interactions already discovered and recognized in particle physics overlap each other. Burt suggests that the simplest way to conceive of such a psychic system would be in the analogy of a " field ". But it would be not a field of force, but " of information ". Nor would it occupy space and time, although the field must be capable of exercising some kind of spatio-temporal influence. He describes how two universes could be conceived, one composed of elementary particles having mass and therefore gravitational interaction, but, like most of the man-sized objects familiar to us, no electric charge and therefore no electrical interaction, and the other composed of elementary particles which are subject to electrical interaction, but, like the photon, having no mass and therefore incapable of gravitational interaction. In the actual universe as we know it, certain entities—electrons and protons, for instance—prove to be subject to both kinds of interaction. Hence the two systems, for reasons we cannot even guess, are in some measure linked. This being so, he says, there can be no antecedent improbability which forbids us postulating yet another system and yet other types of interactions (currently being found) awaiting more intensive investigation such as his " psychic " universe.

Perhaps Professor Feinberg is describing this universe in the following quotation: "... In the transformations that occur when particles interact, however, some things remain constant. These are the conserved quantities, such as electric charge and energy. Other quantities change very slowly, such as parity. There is, furthermore, the mysterious fact that the electric charge of apparently unrelated particles such as the proton and the positron are equal. If indeed there is a substratum underlying particle physics, these quantities must be properties of the underlying stuff."

This underlying substratum sounds reminiscent of Dr. Stafford Clark's interpretation of Jung's Universal Unconscious[4]. "From Jung's studies he evolved the remarkable conception that beneath the individual area of unconscious mental experience, there existed a wider reservoir shared in the first instance by all members of any self-contained community. To this he gave the name of the Racial Unconscious.

" Deeper still, and in some way in the depths of the unconscious mind of every human being, there lay a common pool of all known mental life, extending both in time and space to embrace the background to the whole of human existence. This Jung has called the Universal Unconscious.

The easiest and most diagrammatic way to imagine what this conception means is to think of all human experiences and mental life as one vast plateau rising above the surface of the unknown, and separating into a number of mountain ranges, which in turn give rise to innumerable separate peaks. A line drawn just below the level of the tops of the peaks will disclose only a vast number of separate islands projecting above the surface. These are the separate minds and consciousness of living individuals, and the area immediately below the surface in each one of them is that area of unconscious mental life of which we have essayed so necessarily brief a glimpse in the earlier part of this chapter, and with which the detailed study of Freudian psychopathology is essentially concerned. But further down, the shoulders of the peaks spread and merge until the whole joint ranges occur, from which each separate pinnacle has taken origin and to which it owes its solid foundation. This can be compared with the racial unconscious, the shared but totally unconscious mental life of a self-contained community, their common fears and hopes, myths and dreams, of which each may be aware only at times and only in part. Still deeper stands the central plateau, the universal unconscious common to all humanity, upon which rests the whole mental life of mankind."

In parallel with our remarks on C. S. Lewis and mind as distinct from matter we can add to this simile by suggesting that our physical bodies and environment could be likened to the plant ecology of the mountains and plateau. Jung himself might have had some similar thoughts for he wrote "The psyche deserves to be taken as a phenomenon in its own right; there are no grounds at all for regarding it as a mere epiphenomenon, dependent though it may be on the functioning of the brain. One would be as little justified in regarding life as an epiphenomenon of the chemistry of carbon compounds . . . We may establish with reasonable certainty that an individual consciousness as it relates to ourselves has come to an end (in death). But whether this means that the continuity of the psychic process is also interrupted remains doubtful, since the psyche's attachment to the brain can be affirmed with far less certitude to-day than it could fifty years ago." It can be seen that Jung does not mean to imply any biological dependency of Mind.

How well these pictures fit into the "shift of public mood from deism to Pantheism"[24]. But they are far from conclusive. There is still room for orthodox (and unorthodox) religious beliefs. In fact, criticisms of Jung's philosophy include that the Jungian school of psychiatry is mystical, contradictory, obscure, and so all-embracing as to be in effect meaningless. In its defence it can be argued that with so vast and *cosmic* a psychology this is only to be expected. Moreover, the study of Jungian analytical psychology is one that, if approached with application and critical intent, is extremely rewarding and remarkably stimulating.

We have now used the adjective cosmic to apply to Gestalt psychology and to the Jungian school of psychiatry, and we have fleetingly introduced Religion. What better way to conclude this section of the paper than by quoting Albert Einstein (who held Pantheistic views) on Cosmic Religion?

"I maintain that cosmic religiousness is the strongest and most noble driving force of scientific research. Only the man who can conceive the gigantic effort and above all the elevation, without which original scientific thought cannot succeed, can measure the strength of the feeling from which alone such work can grow. What a deep belief in the intelligence of Creation and what longing for understanding, even if only of a meagre reflection in the revealed intelligence of this world, must have flourished in Kepler and Newton, enabling them as lonely men to unravel over years of work the mechanism of celestial mechanics . . . Only the man who devotes his life to such goals has a living conception of what inspired these men, and gave them strength to remain steadfast in their aims in spite of countless failures. It is cosmic religiousness that bestows such strength. A contemporary has said, not unrightly, that the serious research scholar in our generally materialistic age is the only deeply religious human being."

References

(1) "Probability, Judgment and Mind." (1—The Relevance of Mind to Probability and Judgment) by K. W. Harrison. A.S.W.E. *XRS*/13.19/125/67. *J.R.N.S.S.*, **23,** 3 (May 1968).

(2) "Probability and the Weighing of Evidence" by I. J. Good. Griffin & Co. Ltd. (1950).

(3) "Mind and Consciousness" by Sir Cyril Burt from "The Scientist Speculates" by I. J. Good (Ed.) Heinemann (1962).

(4) "Psychiatry To-day" by D. Stafford-Clark. Pelican (1952).

(5) "Psychophysics" by G. Fechner (1860).

(6) "Gestalt Psychology" by Koffka (1935).

(7) "Physics in Transition" by J. Wheeler. *Scientific Research* (May 1967).

(8) "Weight of Evidence, Causality, and False-Alarm Probabilities" by I. J. Good. *4th London Symposium on Information Theory* (Ed. Cherry).

(9) "Principles of Self-Organization" by Von Foester and Zopf. Pergamon Press (1962).

(10) "A History of Experimental Psychology" by E. Boring.

(11) "Body and Mind in Western Thought" by Joan Wynn Reeves. Pelican (1958).

(12) "A Primer of Freudian Psychology" by Calvin S. Hall. Mentor Books (1954).

(13) "Man on His Nature" by Sir Charles Sherrington. Pelican (1951).

(14) "Dianetics" by L. Ron Hubbard.

(15) "Out of the Silent Planet" by C. S. Lewis. John Lane: The Bodley Head (1939).

(16) "Biological Entropy Pumps". *Nature,* **215,** (September 16, 1967).

(17) "Times Arrow and Information in the Universe" (correspondence). K. Popper and W. Buchel. *Nature* (January 21, 1967).

(18) "Ordinary Matter" by G. Feinberg. *The J. Phil.*

(19) "The Structure of Matter" by R. Bernhard. *Sci. Res.* (March 1967).

(20) "A Use for Plausibility in Radar Probability Theory" by K. W. Harrison. *J.R.N.S.S.*, **21,** 6 (Nov. 1966) 308.

(21) "The Power of the Logistic Function" by K. W. Harrison. *J.R.N.S.S.*, **23,** 2 (March 1968).

(22) *J. Behavioural Sci.*, **7** (1962), 395.

(23) "Do Quantum Jumps Exist?" by E. Schrodinger. *J. Phil. Sci.* (August and November 1952).

(24) "The Philosophical Impact of Modern Physics" by M. Capek. Van Nostrand (1961).

(25) "Contributions to the Founding of the Theory of Transfinite Numbers" by G. Cantor. Dover Publications Inc.

(26) "Asymptotic Growth Curves in the Assessment of Radar Performance", by K. W. Harrison. *J.R.N.S.S.*, **22,** 6 (November 1967) 350 - 354.

STABILITY AND CONTROL OF SUBMARINES

Parts VIII-XI

PART VIII. THE CONSIDERATION OF MOTION WITH SIX DEGREES OF FREEDOM.

J. B. Spencer, B.Sc., R.N.S.S.
Ship Department, Ministry of Defence

Introduction

The simplified equations of motion were developed in Part III and analyzed in Parts IV and V, and throughout this contribution a number of comments have been made on the assumptions involved and the validity of the resulting equations. The principal conclusion is that the assumptions made in the derivation of the simplified equations are least unrealistic in application to the longitudinal motion. This is because motions in the vertical plane cannot greatly exceed the realm of small disturbances (without some discomfort), and furthermore uncalled for changes in speed do not make a nonsense of the "null-speed" concept. Whereas in the horizontal plane of motion neither of these factors can be used to justify the assumptions. It is also difficult to justify the validity of the assumption that the lateral and longitudinal modes of motion are independent, clearly if the submarine rolls the rudders begin to act as hydroplanes and *vice versa*. Furthermore there is the bridge fin, a prominent asymmetrical feature that induces rolling and other cross-coupled motion effects.

In view of these shortcomings in the simplified equations of motion it is apparent that some effort should be made to relax some of the restrictions imposed by the assumptions. The steps taken in this direction depend upon the problem under consideration, clearly from what has been said the assumptions are not unrealistic when applied to purely vertical plane manoeuvres, unless speed changes are to be considered in which case the axial force equation will be required. However, in any manoeuvre involving the use of the rudder equations of motion with six degrees of freedom should be used, and where possible cross-coupled effects included.

The discussion that follows is by no means exhaustive, rather a collection of ideas perhaps worthy of further investigation. Sufficient should have been learnt from the study of the simplified equations to appreciate that any method must ultimately depend on the experimental rather than the theoretical determination of the hydrodynamic forces. This factor has been the guiding light to the methods that are described in the following pages.

Three-dimensional Equations of Motion

The general dynamical equations of motion for a rigid body with respect to moving axis were presented in Part III. Re-writing these equations assuming the products of inertia to be zero:—

$$\left.\begin{aligned} m(\dot{u}-rv+qw)&=X\\ m(\dot{v}-pw+ru)&=Y\\ m(\dot{w}-qu+pv)&=Z\\ I_x\dot{p}-(I_y-I_z)qr&=K\\ I_y\dot{q}-(I_z-I_x)rp&=M\\ I_z\dot{r}-(I_x-I_y)pq&=N \end{aligned}\right\}\quad \ldots (60)$$

The angles of roll, pitch and yaw (ϕ, θ, ψ respectively) are given by the following relations:—

$$\left.\begin{aligned} \dot{\phi}&=p+q\sin\phi\tan\theta+r\cos\phi\tan\theta\\ \dot{\theta}&=q\cos\phi-r\sin\phi\\ \dot{\psi}&=q\sin\phi\sec\theta+r\cos\phi\sec\theta \end{aligned}\right\}\quad \ldots (61)$$

such that following a disturbance at time $t=o$ the heading at time t is given by:—

$$\psi=\psi_o+\int_o^t\dot{\psi}\,dt$$

Similar relations apply to ϕ and θ, but their initial values ϕ_o and θ_o are usually zero.

The co-ordinates of the centre of gravity of the submarine at time t are given by:—

$$\left.\begin{aligned} x&=x_o+\int_o^t\Big[u\cos\theta\cos\psi+\\ &\quad v(\sin\theta\sin\phi\cos\psi-\cos\theta\sin\psi)+\\ &\quad w(\sin\theta\cos\phi\cos\psi+\sin\phi\sin\psi)\Big]dt\\ y&=y_o+\int_o^t\Big[u\cos\theta\sin\psi+\\ &\quad v(\sin\theta\sin\phi\sin\psi+\cos\phi\cos\psi)+\\ &\quad w(\sin\theta\cos\phi\sin\psi-\sin\phi\cos\psi)\Big]dt\\ z&=z_o+\int_o^t\Big[-u\sin\theta+v\cos\theta\sin\phi\\ &\quad +w\cos\theta\cos\phi\Big]dt \end{aligned}\right\}\quad \ldots (62)$$

where x_o, y_o, z_o are the co-ordinates at $t=o$.

In the problems where there is some requirement to consider motions not adequately represented by the simplified equations, attempts are made to formulate equations (60) with suitable right-hand sides. The equations can then be solved and equations (61) and (62) used to determine the displacements of the submarine from its initial position. The difficulty, of course, still lies in the formulation of the right-hand sides of equations (60).

It is once more assumed that the hydrodynamic forces and moments depend on the instantaneous values of the components of velocity and acceleration. This implies that it has still not been found possible to consider the past history of the motion. It is still assumed that experimental values determined for steady state conditions can be applied in the consideration of transient motion (the so-called quasi-static concept), although the assumption of small disturbances is relaxed and terms higher than first order taken into account. In order to treat the large number of hydrodynamic variables in a systematic way, the hydrodynamic reactions are initially expressed by Taylor series expansions. However, on critical examination of this large number of terms many can be neglected because it is felt that they are of small importance, and many more cannot be considered because there are no reliable methods for obtaining their values. An excellent presentation of the equations of motion, and a review of the state of the art with respect to the hydrodynamic variables has been given by A. Strumpf[21].

The approach adopted in the formulation of Y, Z, K, M, N will be found to be little more than an extension of the simplified approach already described. The formulation of X has not been previously considered, and this will be described in a little more detail.

The Axial Force Equation

The adoption of the " null-speed " concept precluded any further consideration of the axial force equation in the simplified approach. It will be remembered that this concept implied that any change in forward speed was instantaneously compensated by immediate changes in drag and thrust. In fact, in purely straight line motion the forward speed component is more correctly determined by the equation:

$$m\dot{u}=F_p-R_t \quad \ldots (63)$$

where F_p is the propulsive force, R_t is the total resistance of the vessel, and the effect of forward speed changes on both of these terms should be taken into account.

For present purposes, only ahead motion is being considered; it is assumed that the Reynolds number effect is negligible, and that for deep submergence the Froude number is not relevant. Furthermore it is often assumed that the resistance is proportional to the square of the forward velocity component, and in the notation commonly used in these studies R_t is written as

$$-\tfrac{1}{2}\rho L^2X'_{uu}u^2.$$

The "derivative" X'_{uu} is a non-dimensionalized coefficient of resistance which can be obtained by experiment in a towing tank.

It is also worth noting that the effective horsepower is the power required to overcome the total resistance, and thus:

$$E.H.P.=\frac{uR_t}{550}$$

$$\text{therefore } X'_{uu}=\frac{-(E.H.P.).550}{\frac{1}{2}\rho L^2u^3}$$

In the representation of the propulsive force a further assumption often made is that the axial force delivered by the propeller is independent of the flow normal to the axis. Furthermore from a consideration of steady state data the following relation is often applicable:

$$F_p=a_1\frac{K_Q}{J^2}+a_2 \qquad \ldots (64)$$

where K_Q is the torque coefficient, J is the advance coefficient, a_1 and a_2 are constants.

In fact, the propeller torque $Q=\rho n^2D^5K_Q$ and the advance coefficient $J=\frac{u}{nD}$ where n is the propeller frequency and D the propeller diameter.

Thus substituting in equation (64) and rearranging:—

$$F_\rho=a_1\frac{SQ}{2D^3}+a_2\,.\,\frac{\rho S}{2}\,u^2$$

$$=a_3Q+a_4u^2 \qquad \ldots (65)$$

where a_3 and a_4 are constants for a particular submarine.

The propeller torque, Q, will depend upon the driving mechanism which in a submarine may be steam turbine or possibly electric motor. It is not intended to give any detail in this respect, but as an example a typical relation applicable to a steam turbine would be:—

$$Q=M_s\,(a_5+a_6n)$$

Where M_s is the turbine steam consumption, and a_5, a_6 are constants for a particular set of machinery.

Equation (63) could thus be re-written:—

$$m\dot{u}=\tfrac{1}{2}\rho L^2X'_{uu}u^2+a_3Q+a_4u^2 +\tfrac{1}{2}\rho L^3X'_{\dot{u}}\dot{u} \qquad \ldots (66)$$

where it will be noted a term incorporating the derivative $X'_{\dot{u}}$ has been included. This derivative with respect to an acceleration is of a type already discussed. It represents the added mass in the longitudinal direction. Values obtained from classical theories can be used, but for a slender body of revolution $X_{\dot{u}}'$ is negligible. Equation (66) determines the forward speed component for changing engine conditions, and can be solved provided Q is defined, and a_3, a_4 are obtained from propeller characteristics.

There are no terms in equation (66) which represent forces that may produce a speed change other than those representing changing engine conditions, because the equation was derived for straight line motion. In the consideration of the submarine with six degrees of freedom, one of the most important factors affecting the speed of the vessel is the increased resistance of the hull incident to the direction of motion. The submarine could be at some angle of incidence ($\tan^{-1}\frac{w}{U}$) in the vertical plane, or an angle of sideslip ($\tan^{-1}\frac{v}{U}$) in the horizontal plane. The increased resistance due to sideslip is the more important, and as it arises as a result of a transverse component of velocity, and is of the same sign irrespective of the sign of the velocity component, it is incorporated in the axial force equation in the form $\frac{1}{2}\rho L^2X'_{vv}v^2$. Experimental values for X'_{vv} could be determined by measuring the resistance on a model being towed at an angle of sideslip.

Similarly, added resistance is obtained by deflection of the control surfaces, rudder or hydroplane, and these coefficients could also be found experimentally.

Incorporating all of these terms in the axial force equation:—

$$m(\dot{u}-rv+qw)=\tfrac{1}{2}\rho L^3X'_{\dot{u}}\dot{u} +\tfrac{1}{2}\rho L^2X'_{uu}u^2+a_3Q+a_4u^2+\tfrac{1}{2}\rho L^2X'_{vv}v^2 +\tfrac{1}{2}\rho L^2u^2X'_{\delta_r\delta_r}\,\delta r^2+\tfrac{1}{2}\rho L^2u^2X'_{\delta\delta}\,\delta^2 \qquad \ldots (67)$$

Extension of the Simplified Lateral and Longitudinal Equations without Cross-coupling

The particular requirement is to improve the validity of the lateral mode equations of motion, and the remarks in this section apply mainly to the side force (Y) and yawing moment (N) equations. However, it is obvious that if necessary an exactly similar approach could be adopted in the case of the normal force (Z) and pitching moment (M) equations.

The derivatives with respect to angles of incidence are obtained experimentally by towing a model at a number of angles, and plotting the forces and moments against the angle of incidence, or sideslip. In the simplified approach, which was concerned with small disturbances, only the linear part of the graph was considered, and the derivative value obtained from the slope of this portion of the curve. If the angles of incidence are increased to higher values the hydrodynamic

forces do not increase linearly above a certain value. A familiar result is that obtained with an aerofoil, the lift initially increases linearly with incidence, but eventually the slope begins to decrease until the ultimate " stall " when there is a sudden decrease in lift (see Fig. 12). The first attempts at extending the linearized approach took into account the non-linearity of the incidence derivatives by including a further term in the equations of motion. For example the side force with respect to transverse velocity (effectively sideslip angle) instead of being represented simply by $Y_v v$ was represented by $Y_v v + Y_{v|v|} v|v|$. Similar terms were incorporated to cater for the non-linearity in the measured values of Z_w, M_w, N_v and K_v. This approach is, in fact, still used, particularly in the vertical plane (*viz.* $Z_{w|w|}$ and $M_{w|w|}$) where any further extension is not generally felt necessary.

A more realistic approach is possible, at least in theory, if use is made of the rotating arm experimental facility. Practical applications of this method are still being investigated. Hitherto, it has been assumed that not only do the hydrodynamic forces depend upon the instantaneous values of the velocities and accelerations, but also that each of these dependencies can be considered in isolation. Using a rotating arm it is possible to measure the forces and moments produced by simultaneous non-zero values of v, r, δr in the lateral mode, or w, q, δ in the longitudinal mode. Recent extensions to the linearized approach have attempted to use measurements made in this way.

Consider first the case with the rudder fixed in a neutral position. The side force in the simplified equations of motion is given by the two terms $Y_v v + Y_r r$. Using the rotating arm simultaneous values of v and r can be applied to a model and the side force measured. The results can be plotted Y against v for different values of r, and by curve-fitting techniques some function Y(v, r) determined. This function may take the form:—

$$Y = Y_v v + Y_r r + Y_{vvr} v^2 r + Y_{vrr} v r^2 + Y_{v3} v^3 + Y_{r3} r^3$$

It will probably be found that this function can be non-dimensionalized with respect to u, and using non-dimensional derivative notation:—

$$Y = \tfrac{1}{2}\rho L^2 Y'_v vu + \tfrac{1}{2}\rho L^3 Y'_r ru + \frac{1}{u}\Big[\tfrac{1}{2}\rho L^3 Y'_{vvr} v^2 r + \tfrac{1}{2}\rho L^4 Y'_{rrv} v r^2 + \tfrac{1}{2}\rho L^5 Y'_{r3} r^3 + \tfrac{1}{2}\rho L^2 Y'_{v3} v^3\Big]$$

It is perhaps incorrect to use derivative notation in this case where curve-fitting techniques are applied, but it is a convenient notation. A similar function could be obtained for the yawing moment N. At present functions of this form are more commonly used in equations of motion for unstable surface ships, and it is possible to reproduce the type of instability that exhibits a Dieudonné spiral, for further details see References [22] and [23].

A further extension is the simultaneous variation of the rudder angle, and the calculation of a function of three variables. Alternatively a different computing approach could be adopted. In the past it has been almost universal practice to solve equations of motion of vehicles of all types using an analogue computer. However, derivative values have been found to depend on an increasing number of factors, particularly those applicable to space probes. Curve-fitting techniques have been found increasingly inadequate, and a recent development is the use of hybrid computing techniques. The equations of motion are still solved on the analogue machine, but the information for the calculation of the derivatives is stored in a high speed digital computer. The derivatives are then calculated as a sub-routine during the progress of a computed manoeuvre.

Cross-Coupling between the Lateral and Longitudinal Modes

The longitudinal motion of the submarine will not induce motion in the lateral direction because the vessel is symmetrical about a vertical plane (the x−z plane). Submarines are not, however, symmetrical with respect to the x−y plane, the principal asymmetry being the bridge fin, and this appendage induces cross-coupled motion between the planes. Theoretical approaches have considered the bridge fin as an aerofoil of small aspect ratio subject to a velocity normal to its span, v, and an angular velocity r. An aerofoil in this condition will have a ' lift ' force acting upon it, and there will be a circulation about it which can be calculated by classical aerodynamic theories. The ' lift ' force is part of the derivatives Y_v, Y_r, N_v, N_r already measured, but the circulation about the bridge fin induces a circulation about the hull of the submarine (about the x-axis), and this circulation produces a reaction in the direction of the normal force and pitching moment equation of the submarines. Obviously the reaction in the longitudinal mode is in the same direction irrespective of the sign of the velocities v and r, and the calculations have produced effective derivatives denoted by Z_{vv}, Z_{vr}, Z_{rr} and similarly for the pitching derivatives. In non-dimensional notation:—

$$Z(r, v) = \tfrac{1}{2}\rho L^2 Z'_{vv} v^2 + \tfrac{1}{2}\rho L^3 Z'_{rv} rv + \tfrac{1}{2}\rho L^4 Z'_{rr} r^2$$

This method would appear to be largely theoretical despite it being said in the introduction to this chapter that the experimental approach would be the guiding light. Fortunately if a rotating arm

is used the measurement of the reaction in the Z and M directions when a model is subject to velocities v and r is quite a practicable proposition.

Roll-Dependent Motion

The rolling moment equation was discussed in Part V, and in the derivation of the simplified lateral equations of motion in Part III it was assumed that the motion was roll-independent. It is now proposed to re-consider the rolling moment equation, and to relax the assumption of roll-independence by considering how rolling might affect motion in the lateral and longitudinal modes.

The rolling moment equation in simplified form is (equation 29):—

$$(I_x - K_{\dot p})\dot p - vK_v - pK_p - rKr + mg\overline{BG}\phi = K(t)$$

and in early studies it was often considered satisfactory to use in this equation values of the derivatives obtained by theoretical methods. It was assumed that the bridge fin was the major contributor to the various derivatives, and its effect was calculated by considering it as an aerofoil of small aspect ratio. In addition an estimate of the effect of hull friction on the damping in roll, K_p, was also taken into account. However, as has been noted in Reference [1] actual roll angles of submarines are sometimes large enough to create some apprehension on the part of the operators, particularly during the transient phase of the motion. Consequently some effort has been expended on determining the derivative values by experiment, and additional terms have been included in the equations of motion.

The rolling moment due to sideslip, K_v, can be obtained from measurements made on a model towed along a straight path at various sideslip angles, and furthermore some estimate of the non-linearity involved in considering larger displacements can be incorporated by use of the second order derivative $K_{v|v|}$. Similarly it must be obvious from previous discussions that K_r can be obtained from a rotating arm experiment. Another additional derivative that could be measured in a towing tank is the rolling moment due to rudder angle. This is often very small, or negligible, but it is possible that a vessel may have an unbalanced cruciform control surface configuration, with perhaps greater rudder area above the hull than below. In such a case K_{δ_r} may be of significance.

The damping in roll, K_p, could be obtained by the analysis of free or forced oscillations on a model, but the motion is usually so dead-beat as to make measurement of free oscillations extremely difficult. The type of experiment that could be undertaken is illustrated in Fig. 13.

The neutrally buoyant model could be supported fore and aft in relatively frictionless bearings, and the point P_1 made to perform simple harmonic oscillations while being towed along a ship tank. Suppose the point P_1 is displaced to the right by an amount $y = d \sin \omega t$ and the simultaneous displacement of P_2 is ϕh where ϕ is the angle of roll. Then the increase in spring tension is $\sigma(y - \phi h)$ where σ is the spring coefficient.

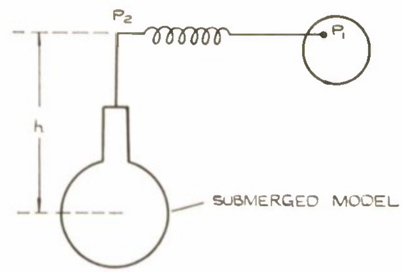


FIG. 13. Diagrammatic representation of model set-up for measurement of roll damping.

The applied moment is thus:—

$$K(t) = \sigma h\,(d \sin \omega t - \phi h)$$

Now the pure rolling moment equation can be written:—

$$(I_x - K_{\dot p})\ddot\phi - \dot\phi K_p + mg\,\overline{BG}\,\phi = K(t)$$

or making the substitution:—

$$a\ddot\phi + b\dot\phi + c\phi = K \sin \omega t$$

where $a = I_x - K_{\dot p}$, $b = -K_p$, $c = mg\,\overline{BG} + \sigma h^2$, $k = \sigma dh$

In the steady state motion which is eventually achieved the model will oscillate such that:—

$$\phi = \phi_o \sin(\omega t + \varepsilon)$$

where ϕ_o is the amplitude, and ε the phase lag.

From the above equations the following relations can be determined:—

$$\phi_o{}^2 = \frac{K^2}{(c - a\omega^2)^2 + b^2\omega^2}$$

$$\tan \varepsilon = \frac{b\omega}{c - a\omega^2}$$

In a particular experiment values of k and ω are known, and values of ϕ_o and ε can be measured.

Thus if m, $\overline{BG}$ and σ are known it is possible to determine K_p and $(I_x - K_{\dot p})$.

The rotation of the propeller will also have some influence on the rolling of the vessel; this effect is usually compensated for by an off-set in the control surfaces at the stern thus providing an equal and opposite rolling moment. Occasionally an attempt is made to include these terms in the equations of motion, the torque produced by rotation of the propeller being determined from propeller

characteristics which may have been obtained in a cavitation tunnel.

Apart from knowledge of the mass and inertia of the submarine, present day requirements thus demand some details of the following derivatives:—$K_{\dot{p}}$, K_p, K_v, $K_{v|v|}$, K_r, K_{δ_r}, and possibly the rolling movement produced by the propeller.

The derivatives most commonly used to represent the effect of rolling on motions in other directions are Y_p and N_p, and even though it is thought that there are only two significant derivatives, there is a very limited amount of information available with respect to their values. Y_p can be calculated, if it is assumed to arise entirely from the presence of the bridge fin. Thus if a fin area A is assumed to have a centre of pressure height z_f above the centre of gravity of the submarine, then the effective angle of incidence of the fin at the centre of pressure during a roll is given by $\frac{pz_f}{u}$. The lift (or in this case side force) on the bridge fin is given by:—

$$Y = -\tfrac{1}{2}\rho A u^2 C_L \qquad \ldots (68)$$

where C_L is the lift coefficient for the fin, and this can be calculated using aerofoil theory. Weinig's method for wings of small aspect ratio was introduced in Part VI, and using his method based on the lifting line theory:—

$$C_L = \frac{a_o}{1 + \frac{a_o}{\pi AR_e}} \xi_L \cdot \frac{pz_f}{u} \qquad \ldots (69)$$

where a_o is the lift slope of the bridge fin section, AR_e is the effective aspect ratio including a hull image (due to the proximity of the hull) and ξ_L is the Weinig correction (which is the ratio of his result (equation (52)) to the simple lifting line result (equation (50)).

Thus non-dimensionalizing:—

$$Y_p' = -\frac{Az_f}{L^3}\left(\frac{a_o}{1 + \frac{a_o}{\pi AR_e}}\right) \xi_L$$

The value of the yawing moment with respect to roll velocity, N_p, is usually assumed equal to the rolling moment with respect to yaw rate, K_r, which was measured by experiment. The validity of this assumption in a simple case considering only the bridge fin can be shown quite easily. From equations (68) and (69) the side force on the bridge fin due to roll is given by:—

$$Y = -\tfrac{1}{2}\rho A u a_1 z_f p$$

where $a_1 = \frac{a_o}{1 + \frac{a_o}{\pi AR_e}} \cdot \xi_L$

and thus if the centre of pressure of the bridge fin is distant x_f from the centre of gravity the yawing moment is given by:—

$$N = -\tfrac{1}{2}\rho A u a_1 x_f z_f . p$$

Considering yawing motion instead of rolling, the effective incidence of the centre of pressure of the fin is now given by $\frac{rx_f}{u}$, and the side force on the fin is given by:—

$$Y = -\tfrac{1}{2}\rho A u a_1 x_f r$$

The rolling moment is thus:—

$$K = -\tfrac{1}{2}\rho A u a_1 x_f z_f r$$

and it is seen that $K_r = N_p$

PART IX. EMERGENCY MANOEUVRES, AUTOPILOTS, AND DISPLAY SYSTEMS.

Introduction

The simplified equations of motion were analyzed in Parts IV and V and the application of the results of the analysis to the design of suitably stable and controllable submarines was indicated. Stability in the vertical plane was discussed in Part IV, and criteria given which had to be satisfied for metacentric and straight line stability (and hence directional stability). In the design process adjustments to the size of the fixed stabilizer fins can be made to give more or less stability. It was also shown that the damping coefficient can be calculated for the operational speed range of the submarine, and servo-mechanism theory indicated suitable values of about 0·7. Controllability was assessed from the predicted performance in a number of specific manoeuvres, such as the overshoot manoeuvre. Motion in the horizontal plane was discussed in a similar manner in Part V, once again criteria for straight-line stability were given, and specific manoeuvres described.

On the basis of predictions of this nature it should thus be possible to design a submarine that has adequate stability and manoeuvrability, provided, of course, that the basic hydrodynamic data are reliable. However, the shortcomings of the simplified equations of motion have already been indicated, and there are other aspects of sub-

marine performance where prediction is of value and which require the use of the more complicated three-dimensional equations. Examples of this type of problem are given in the following paragraphs.

Emergency Manoeuvres

The failures most likely to lead to catastrophe are those involving loss or jamming of the control surfaces, and fractures resulting in flooding of some sections of the submarine. There are a number of procedures that can be taken in the event of such an emergency, and the submariner is obviously anxious to know which are the most effective. Predictions of the effect of the failure, and the recovery procedures are calculated with a view to giving guidance on the procedure to be adopted. Such calculations involve the representation of the submarine with six degrees of freedom, and in such extreme manoeuvres the applicability of the equations of motion is probably stretched up to and perhaps beyond reasonable limits. Of course, it is not really possible ever to check the complete validity of the predictions.

The particular failure it is required to study is simulated by its representation as forces and moments for inclusion in the equations of motion. The terms representing the effect of control surface deflections have already been considered, and it is clearly quite a simple matter to represent a surface jammed in any position. Solution of the equations of motion thus provides the result of any such failure if no corrective action is taken. Loss of a control surface is a similar problem, if the driving mechanism breaks, the surface will trail at some angle dependent upon the 'balancing' of the surface. This angle is usually known, it is not always a neutral angle, and can be simulated.

Flooding is less amenable to representation in simple mathematical terms. The location in the vessel, and the size of the fracture can be varied, but assumptions must be made about the type of flow through the orifice. The rate of influx of sea water depends upon the depth of the submarine which is determined by the equations of motion, but it also depends upon conditions inside the submarine. The flow of water into a specific compartment will depend upon the pressure build-up inside that compartment, and this again depends upon action by the crew. The effect of flooding can obviously be reduced by restricting the flooded volume to as small a compartment as possible, and if the compartment is quite small, some benefit can be obtained by pressurizing with air. It is usual in these studies to neglect the effect of back-pressure, although it is assumed that flooding is restricted to specific compartments. Even considering a single compartment, flooding is not easy to simulate, since the motion of the submarine will cause the water to move about and so vary the direction of the force it exerts. The extent to which all these factors can be taken into consideration depends upon the computing facilities available, but very often a number of assumptions are made, and the representation is such that water is assumed to flow into the hull at a rate given by the formula for a free orifice (*i.e.* not drowned):—

$$Q_F = AC_D\sqrt{2gh}$$

where Q_F is the flow rate (cu ft/sec)
A is the area of the hole (sq ft)
h is the depth of the submarine (ft)
C_D is the coefficient of discharge through the hole (typically 0·6)

The force exerted by the water is obtained by integration with respect to time, and resolution along the axes used for the equations of motion. The moment arm about the centre of gravity of the flooding compartment is assumed to be an average value of arms calculated for different flooding levels at different attitudes.

The recovery procedures must be dealt with in a similar manner. In emergencies there are a number of courses of action that can be taken; these usually involve some combination of the following:—

(i) using astern thrust (*i.e.* reversing the propeller) to bring the submarine to rest.

(ii) using the rudder to slow down the ahead motion of the submarine.

(iii) making the submarine positively buoyant by blowing some of the ballast water out.

In the event of jammed hydroplanes all three of the above procedures will probably be applied, and in calculations assumptions have to be made with respect to the time taken by the crew to appreciate the fault, and the time taken by them in initiating the recovery procedure.

The simulation of the effect of astern thrust is the most difficult, the reversal of the direction of rotation of the propeller will have an appreciable effect on the flow over the after end of the submarine. The derivative values will undoubtedly change, in particular those referring to the forces and moments on the control surfaces which are just forward of the propeller. Obviously this is not a problem amenable to solution by any of the methods so far described, and it is doubtful if a realistic mathematical representation will ever be found. A simple method would be to consider that reversal of the thrust increased submarine resistance, the amount of increase being estimated from the results of experiments and full-scale trials. The

effect of the reversal on the derivatives is neglected; in the case of the control surfaces the effect on hydroplanes jammed in a bow dive attitude is likely to be beneficial, in that a breakdown in flow will reduce their effectiveness. On the other hand, the effectiveness of the rudder will be also reduced, and the rudder is very effective in reducing ship speed and thus assisting recovery.

The rate at which it is possible to expel water from the ballast tanks is dependent on a number of factors, such as the size of orifice, the depth below the surface, and the pressure of air available. There are also a number of relatively unknown factors such as the rate of delivery of air when the pipes are subject to icing due to the sudden expansion, and the differential pressure that it is possible for the emptying ballast tanks to sustain. If it is assumed that there is no restriction on the egress of water then a typical relation for the amount of water blown out in t secs is:—

$$Q_B = \frac{RT}{h}\int_0^t q_t \, dt \text{ (in lbs/sec)}$$

Where q_t is the rate of flow of air in lbs/sec., h is the depth of the ballast tank at time t

R is the gas constant

and T is the absolute temperature.

Furthermore, assuming that there is no icing or other restrictions on the flow of air, the rate of flow q_t is given by:—

$$q_t = q_o \, e^{\frac{q_o t}{w}}$$

where q_o is the initial rate of blow (lbs/sec) at $t=o$

and w is the initial weight of air in the storage bottles.

With this type of representation of the emergency and the recovery procedures it is possible to calculate the results of innumerable manoeuvres, and estimate which procedure is most likely to succeed. In the case of jammed after hydroplanes at low speeds the situation is not too dangerous, and it should be possible to get back to the surface by reducing speed, using forward hydroplanes, and perhaps blowing ballast, and there is time to undertake this procedure in a controlled manner. At high speeds if the after hydroplanes jam at an appreciable angle of dive, only immediate action can prevent the situation becoming catastrophic. In order to prevent the submarine exceeding collapse depth speed must be reduced as quickly as possible. Obviously reverse thrust must be applied by the propeller, and the application of rudder is extremely effective. Unfortunately the application of large rudder angles produces large snap roll angles which are, to say the least, disconcerting, also an initial increase in dive angle may be produced. In order to avoid these effects it has been suggested that the rudder could be oscillated from side to side, but this method is not so effective in reducing speed. If speed is not reduced the blowing of ballast water is quite ineffective, nevertheless it is worthwhile beginning the operation as soon as the emergency is appreciated, then as soon as the speed is reduced there will be a certain amount of positive buoyancy already available. The danger here is that nearing the surface the amount of positive buoyancy will increase rapidly due to expansion of the air, and unless some care is taken the vessel may break surface at some alarming attitude. The forward hydroplanes are not particularly effective at high speeds, although naturally they would be used to assist recovery. Conversely jammed forward hydroplanes could be easily overcome by use of the after hydroplanes.

In the consideration of flooding a most important factor is whether the flooding is in such a location as to cause loss of power. If the flooding is aft it is the more likely that power will be lost in which case unless the rate of blowing of ballast can exceed the rate of intake of water there is little hope of recovery from an initial deep situation. At intermediate depths the speed of the submarine at the instant of flooding is important, because the hydrodynamic forces on the hull can carry a certain amount of negative buoyancy. This indicates that when operating at these depths speeds ought to be kept above a certain minimum value, but this would make recovery from a possible jammed hydroplane less likely. If flooding does not cause loss of power, in all cases it is found advantageous to increase to full power, and attempt to rise to the surface at a pitch angle of about 30 - 40°. There are a few cases when it can be shown that it is not the most effective procedure to blow all ballast, but in general the blowing of all ballast should usually be initiated, and changes made in the procedure if it is found that the submarine is assuming excessive and uncontrollable pitch or roll angles. Computer calculations considering the various procedures have been analyzed, and curves produced showing the maximum rates of flooding from which recovery could be achieved, assuming the flooding to occur at a variety of initial conditions of depth and speed.

The calculated responses have been useful in cases such as this in indicating the most effective procedure to adopt, and perhaps also could be used to decide upon the limits of safe operation for any particular class of submarine. Computer simulations are also of considerable value in the

prediction of the performance of other proposed schemes which might aid recovery. Making use once more of techniques developed for aircraft, dive brakes and even parachutes have been investigated, but the most apparently successful scheme so far considered is the X-configuration stern.

The typical submarine considered throughout this note has a cruciform arrangement of after hydroplanes and rudders just ahead of the propeller. The X-configuration has the location of its four control surfaces rotated through 45°, as the configuration X implies. Diagonally opposite surfaces are still coupled together (as for the cruciform arrangement), and thus to dive without turning, or to turn without diving, it is necessary to move both pairs of surfaces. This requirement increases the complexity of the control system, but an advantage is to be gained if it should happen that one pair jams in a dive position, the other pair are available to supply an opposite and at least equal force in the vertical plane. The resultant deflection is equivalent to a rudder movement, but it is far better to complete a horizontal circle than attempt a vertical loop. A further advantage of the X-configuration is that, if necessary, control surfaces of greater span than those of the cruciform arrangement can be used without the tips protruding beyond the maximum beam and depth of the submarine hull. The disadvantage is undoubtedly that this configuration increases the complexity of control, in order to be able to execute dives without an element of turn, the four control surfaces must be set with great accuracy.

Auto-Pilot Design

Although the control of a submarine becomes increasingly like that of an aircraft, unlike an aircraft the actual movement of the controls is often entrusted to the most junior members of the crew, rather than the most senior. Until comparatively recently this practice has resulted in a rather unnecessary waste of manpower, there being one man for each pair of hydroplanes, another for the rudder, and a supervizing officer. Furthermore the operation of the hydroplanes was such that the forward planesman controlled depth, and the after planesman the pitch angle of the submarine. Thus unless both men were skilled and worked as a team, any and every vertical plane manoeuvre could be undertaken with the maximum amount of inefficiency. It is more usual to find one-man control stations in the modern submarines, and many are fitted with auto-pilots.

One man control stations use " joystick " control for hydroplanes and rudders as in aircraft. Because there are two sets of hydroplanes adjustment has to be provided so that the stick moves both sets in any chosen (and variable) ratio. For instance, at higher speeds the forward hydroplanes are relatively ineffective, and after hydroplanes only are required. Auto-pilots merely replace the man and move the control surfaces in the same way, but they are generally more efficient, particularly over long periods of time.

An auto-pilot could be electrical, hydraulic, or even pneumatic provided its output was able to initiate movement of the relevant control surface. The operating medium is immaterial to this discussion which is concerned with the principles. In the vertical plane the auto-pilot is required to maintain depth, and it is obviously also desirable that it controls pitch angle. A simple control operating on the errors in each of these variables would move the hydroplanes in accordance with the following equation:—

$$\delta = a \left[(z_0 - z) + b\theta \right] \quad \ldots (70)$$

where δ is the hydroplane angle,
z_0 is the ordered depth,
z is the actual depth,
θ is the pitch angle

and a, b are constants which can be varied with changing operational conditions. It is assumed that the desired pitch angle is zero.

It is obvious from equation (70) that zero hydroplane angle would be obtained with zero depth error and zero pitch angle, and this is only a steady state situation if the submarine happens to be perfectly balanced under these conditions. In fact this is not necessarily the case, as has already been indicated it may be necessary to set a non-zero balance angle on the hydroplanes in order to hold a level course at level trim. The auto depth control would obviously have to operate with the balance angles as the effective zero hydroplane angles, and have a means provided to adjust this off-set zero for various conditions. However, if an equation of the form of equation (70) were used there would be small errors due to changing conditions, and hence steady state errors in ordered depth, and pitch angle. These steady state errors would only assume noticeable proportions if there was some marked change in the hydrodynamic forces on the submarine, and the most likely cause of such a change is when the submarine makes a turn. Thus a steady state solution (assuming the turn is long enough to reach a steady state) could be such that there would be a depth error of 30 ft, a pitch angle of 7°, and an after hydroplane angle of 10° (assuming that only the after hydroplane were being used to control depth). The errors would, of course, reduce to zero on completion of the turn, and the depth error could be reduced during the turn, if this were thought necessary, by adjustment of the ordered depth control.

A depth control of this form would in fact operate reasonably satisfactorily. This is undoubtedly due to the " look-ahead " provided by the pitch angle component of equation (70). (z_o-z) is the depth error measured at a particular instant of time, but the term $b\theta$ is in effect the additional depth error due to pitch angle error, and the depth given by $(z_o-z)+b\theta$ would be the point reached after the submarine had travelled distance b from the point where depth z was measured, assuming that the vessel was travelling with zero angle of incidence.

A more sophisticated form of control equation would include terms dependent on the rates of change of depth and pitch angle, and furthermore the equation would be so arranged that adjustable limits could be applied to limit pitch angle to a desired maximum. It would also be a comparatively simple matter to limit hydroplane movement.

Similarly in the production of an automatic heading control some phase advance is found advantageous, and control basically is of a form such that the desired rudder angle is given by:—

$$\delta r = \frac{-K\ (1+a_1p)}{(1+a_2p)\ (1+a_3p)}(\psi_D-\psi)$$

where ψ_D is the desired heading angle

ψ is the measured heading angle

and K, a_1, a_2, a_3 are constants, variable for differing operational conditions. Here again it is a comparatively simple matter to limit rudder movement.

Early versions of the automatic pilots were designed using analogue computers to check the performance at each stage of development. In a calculation of this type the solution of the equations of motion of the submarine provide the depth, pitch angle, and heading angle at any instant of time, these values are used continuously to calculate the desired hydroplane and rudder angles, which are then fed back into the equations of motion. Obviously if a control loop of this nature is stable, there is no deviation from the steady state condition unless some form of disturbance is deliberately applied. In the first instance, disturbances involving the selection of different ordered depths and heading angles were considered, and the submarine response calculated. It is generally found that to obtain optimum response throughout the speed range, some adjustment of the control parameters is required. Some sophisticated control systems have this variation automatically applied (the so-called adaptive controls), but in many cases it is not worth the extra complication, and adequate performance is achieved by use of average values of the parameters.

Because of the difficulties of analyzing the motion of a vessel on or near the surface of the sea, this introductory note has been concerned largely with the deeply submerged submarine. In particular, the design of an auto-pilot for deep submergence is a comparatively simple matter, but to be of any use to the submariner the control should be able to operate when subject to the disturbances experienced on or near the surface. The simulation of the hydrodynamic forces on a submarine hull due to wave disturbance is an extremely complex problem which will be briefly discussed in the next paragraph, but provided some reasonably approximate representation is available the assessment of the performance of a control system is amenable to solution by simulation techniques. In this case, the representative disturbance is fed into the equations of motion of the controlled submarine; over a period of time the deflections of the vessel from its desired path, and the amounts of control surface angle used can be calculated and recorded. These results are then analyzed by statistical methods and the performance of different control systems compared.

The Simulation of the Disturbance Produced by Waves

There have been a number of methods proposed for the calculation of the forces and moments on a submerged body moving under waves. In many investigations of submarine motion absolute realism is not required in the simulation of the surface disturbances, and almost any of the methods could be used. However, just occasionally requirements have arisen to hold a submarine absolutely steady, and to design a control system for this situation demands a more thorough knowledge of the forces the controls have to overcome. Here again the very proliferation of reports on the analysis of the sea surface and its effect on ships and submarines, suggests that as yet no one method has been entirely successful.

The classical theories considered spheroidal bodies beneath a regular sinusoidal wave; such a theory was developed by Havelock[24]. The results of this, and similar studies, have been used in a number of simulations; indeed the forces and moments calculated by these methods may well reasonably represent the forces experienced by a submarine under the elusive " long-crested " sea. More recently it has been assumed that the forces do not vary sinusoidally, as in the above theories, but vary in accordance with the irregularity of the sea surface. A major problem is, of course, the representation of the sea, and since the application of spectral techniques[25] to the study of ship motions, a number of workers have derived what they consider reasonable spectral formulations of

the sea surface. Reference [26] gives formulae used for calculating the wave spectra which were derived by Darbyshire, Neumann, Moskowitz and the British Towing Tank Panel. The formula due to Moskowitz is of interest in that it is the result of analysis of some 400 recordings of the actual sea state.

In actual fact the Neumann spectrum was used in a number of early simulations, this spectrum being given by the formula:—

$$0{\cdot}00271\ f^{-6} \exp(-18{\cdot}41\ f^{-2}\ W^{-2})\quad ft^2\ sec$$

where f is the frequency (cps) and W the wind speed (knots). The spectrum produced by the above formula, upon substitution of a particular value of the wind speed, was thought by Neumann to give the frequency content of a fully developed sea surface produced by the assumed wind. For the purposes of computer simulation the signal from a white noise generator (white noise contains all frequencies in equal proportion, its spectrum is flat) was suitable filtered so that the filter output had a spectrum approximately the shape of the Neumann spectrum.

In the assessment of a submarine control system it is not essential for any simulated disturbance to be absolutely correct, even if this was possible. A simulation of the form described above, in which the external forces and moments on the submarine vary in an irregular manner is often found adequate, except when it is necessary to reproduce the forces experienced by a vessel operating near the surface which appear to attract it to the surface.

It is well known that motion in a fluid due to a surface wave disturbance decreases with increase in depth. Particles in the fluid subject to surface wave disturbance move in an orbital path which becomes smaller on increase of depth. Thus any body moving within a region where the fluid motion is still noticeable will have fluid moving along its upper surface at a greater velocity than that moving along its lower surface. This effect is thought to provide a lift force on the vessel which depends upon its depth below the surface. Undoubtedly the force exists but theories are not very successful in predicting its magnitude. In fact in this whole field of predicting the forces on a submarine beneath a disturbed sea there is room for more investigation, experimental and theoretical. The lack of detailed knowledge is the main reason why this note has been almost entirely restricted to the consideration of deeply submerged vessel, where the effect of surface disturbance is not noticeable.

Display Systems

Although automatic control of a vessel is the most economic and efficient method, it is necessary (*e.g.* in the event of emergency) to be able to revert to manual control. If the human operator is required to assume control for long periods, and also be able to make full use of the submarine's manoeuvrability, it is essential that he be provided with an adequate display system.

Using only a basic presentation a single operator would have to keep an eye on hydroplane angles (after, and occasionally forward also), pitch angle, depth, rudder angle and heading angle. Thus five or possibly six indicators have to be monitored, and it is quite impossible to undertake, with accuracy and safety, many of the manoeuvres of which a submarine is capable. Using the archaic method of split control requiring two or three operators may show some improvement in this case, but because of interaction control is still going to be highly inefficient. However it is possible for one man to achieve satisfactory control, provided that he is supplied with a suitable display, which in this context requires a reduction in the number of instruments to be monitored, and the introduction of "quickening ".

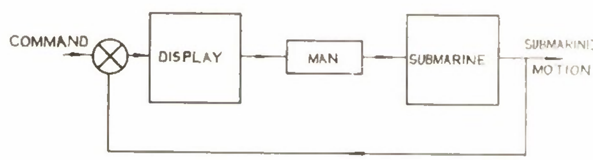


FIG. 14. Block diagram of submarine control loop.

In the control of a submarine man is an element in a rather complex closed-loop feedback system, as is shown in Fig. 14.

In any system of this type it is highly desirable that the man is required to act at no more complex a level than a simple amplifier, despite the fact that man is the most adaptable control system available. If operation as a simple amplifier is all that is necessary, the human operator will be able to operate quite satisfactorily for reasonably long periods of time. In order to achieve this aim the technique of display quickening is adopted.

Using an unquickened display of basic instruments the operator sees, in effect, an error signal in each of them, and by his built-in capability of rate estimation (*i.e.* approximate differentiation) he is able to move his controls in a manner approaching that which is required. However the more complex the system the more inaccurate this estimation becomes, and more errors appear in the output. A quickened display system is designed to carry out any necessary differentiation and reduce the role of the operator to that of the simple amplifier. Thus, whereas for the unquickened system the operator viewed an error signal of the form $(\theta_i - \theta_o)$ where θ_i is the command

input, and θ_o the motion output, with the quickened system he sees an error signal of the form $\theta_i-(k_1\theta_o+k_2\dot{\theta}_o+k_3\ddot{\theta}_o)$.

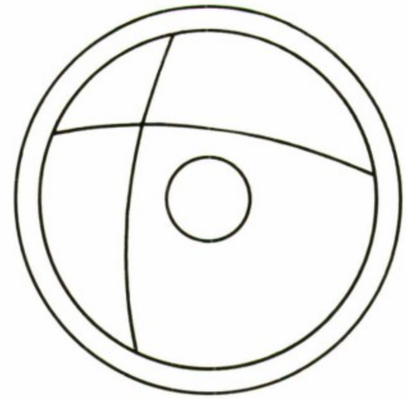
This then is the general approach to quickened display systems, and a number of sophisticated designs have been evolved. To illustrate the point a very simple display system developed some years ago, which proved quite satisfactory on a simulator, will now be described.

In the description of automatic controls, it will be remembered that the hydroplane angle was given by a relation of the form $\delta=f(h,\theta)$ where h is the depth error, and θ the pitch angle error. Similarly the rudder angle was given by a relation $\delta r=f(\psi)$ where ψ is the heading angle error. Thus at all times the following relations should be true:—

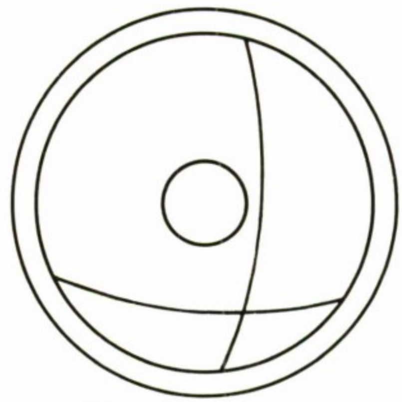
$$f(h,\theta)-\delta=0$$
$$f(\psi)-\delta r=0 \quad \ldots (71)$$

although because of delays in the movement of the control surfaces there will be discrepancies for short periods of time. Suitable functions $f(h,\theta)$, $f(\psi)$ including derivatives of the variables, have been devised during the development of automatic controls. If then the signals given by equations (71) are fed to a suitable instrument, this device would perform a useful monitoring function for an autopilot, since the deflections should be on or about zero if the autopilot is working satisfactorily. An aircraft instrument was used in the simulation in which the two equations (71) could be used to deflect two moveable cross wires, and for satisfactory operation the cross-wires should cross near the centre of the display.

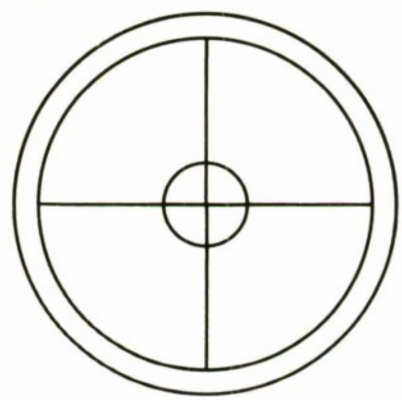
If now the autopilot is disconnected, and the human operator put in charge of the controls, the cross-wires of the display should still cross near the centre of the instrument, provided that the man has applied approximately the correct amount of control surface angle. The human operator is thus merely replacing a simple mechanical linkage, and the only deterioration in the performance of the overall system is that introduced by the poorer reaction time of the human being. A diagrammatic representation of the display is shown in Fig. 15, and using this display it was possible on the simulator to undertake the most complicated manoeuvres with little or no previous experience. It should be noted, of course, that using a display of this type the operator has no knowledge of his position or the angles used. However if the operator is the most junior member of the crew knowledge of position is not essential to him, in any case the conventional instruments recording depth *etc.*, would undoubtedly be close at hand. A more important aspect is the possibility of limited control surface, and attitude angles being required;



(a) ACTION REQUIRED.
Stick movement to Right and Back



(b) ACTION REQUIRED.
Stick movement to Left and Forward



(c) NO ACTION REQUIRED.
On course at correct depth

FIG. 15. An experimental submarine control display system.

Since this contribution was written a paper has been published in the *Naval Engineers' Journal* (December 1966) which gives details of American studies of emergencies and recovery procedures. It is cntitled "Overcoming Submarine Control Surface Jams and Flooding Casualties" and is by A. J. Giddings and W. J. Louis.

these limitations can be applied in the same way as for the autopilot, leaving the operator free to use the display system without reference to other instruments.

The more sophisticated display system is typified by the system which carries a high-speed computer which continuously calculates the submarine's position at some time in the future, should the control surfaces be held fixed in the position they are in at the instant of calculation. If this future position is displayed on a cathode ray tube, and also the desired future position, it is obviously the function of the operator to maintain coincidence between the two.

PART X. FULL SCALE TRIALS, INCLUDING ASYMPTOTIC RESPONSE METHODS.

Introduction

The preceding parts of this contribution have been concerned with the development of a theory for predicting submarine performance, and the ultimate check of the usefulness of any such theory is, of course, in the performance of the full-scale vessel. A number of specific manoeuvres have already been described, and the comparison of the predicted and actual performance of such manoeuvres is likely to be part of any trials programme. However, a study of the theory suggests that it should be possible to obtain more basic data from full-scale trials, in particular actual derivative values. Some possible methods are given in this chapter although it must be remembered that full-scale trials are more difficult to control than model experiments, and it is not easy to perform accurately even the simplest of manoeuvres.

Determination of Z_w' and M_w'

Consider the vertical plane of motion, and assume that the motion of the submarine is adequately described by the simplified longitudinal equations. Thus if the submarine has forward and after hydroplanes (angular deflections δf and δa), the equations of motion are:—

$$(m'-Z_{\dot{w}}')\dot{w}'=(m'+Z_q')q' + w'Z_w'+Z_*'+\delta f Z'_{\delta_f}+\delta a Z'_{\delta_a}$$

$$(I_y'-M_{\dot{q}}')\dot{q}'=q'M_q'+w'M_w' - m'\gamma\int q'd\tau+M_*'+\delta f M'_{\delta_f}+\delta a M'_{\delta_a} \quad \ldots (72)$$

It is assumed that the submarine is in a neutrally buoyant condition, but the terms Z_*' and M_*' have been introduced which represent the force and moment on the vessel when it is proceeding straight and level at zero pitch angle. Z_*' and M_*' may be due to asymmetry in the body of the vessel, and are the force and moment which require a non-zero hydroplane angle (*i.e.* balance angle) to hold the submarine in a level path. It is further assumed that values of the hydroplane derivatives which have been determined for a model (*i.e.* towing tank experiment) can be applied to the full-scale ship.

Some of the terms of equations (72) are zero in steady state conditions, and if a submarine is made to proceed at constant depth while the hydroplanes are adjusted to achieve steady state conditions for a number of different pitch angles, including zero, the angles recorded should satisfy very simple relations. Trials could also be undertaken at different speeds, but non-dimensionalized results should be speed independent. Angular deviations must not be large enough to invalidate the assumption of small disturbances.

For the submarine at constant depth in level trim equations (72) reduce to:—

$$O=Z_*'+\delta f Z'_{\delta_f}+\delta a Z'_{\delta_a}$$

$$O=M_*'+\delta f M'_{\delta_f}+\delta a M'_{\delta_a} \quad \ldots (73)$$

Substituting into the above equations the recorded values of the hydroplane angles that were required to hold the submarine in level trim, it is possible to obtain Z_*' and M_*' by using the assumed values of the hydroplane derivatives.

In those conditions in which the submarine is not in level trim, but is proceeding along a level path at some non-zero pitch angle, then the following equations should be satisfied:—

$$O=w'Z_w'+Z_*'+\delta f Z'_{\delta_f}+\delta a Z'_{\delta_a}$$

$$O=w'M_w'-m'\gamma\theta+M_*'+\delta f M'_{\delta_f}+\delta a M'_{\delta_a} \quad \ldots (74)$$

and furthermore in such steady states w', the angle of incidence is equal to the pitch angle θ. Thus using the first of equations (74) the values of Z_*,

Z'_{δ_f} Z'_{δ_a} would be known, the values of δf, δa and w′ should have been recorded at each steady state condition, and hence $w'Z_w'$ is calculable for each case. Plotting $w'Z_w'$ against w′ for a number of different conditions (bow-up and bow-down) should obviously produce a straight line of slope Z'_w, for the small angles used.

In order to determine M_w' the second of equations (74) is used and a similar procedure adopted but, in this case, some prior knowledge of the mass and metacentric height of the submarine should be available. The equation can only be solved if values of m′ and γ are known.

The difficulties of this method are apparent, apart from the assumptions that have to be made, the trial runs themselves are not easily undertaken, steady states are difficult to achieve. It is more difficult to devise a method for the direct determination of Z_q' and M_q', but an interesting possibility depends upon the following theory.

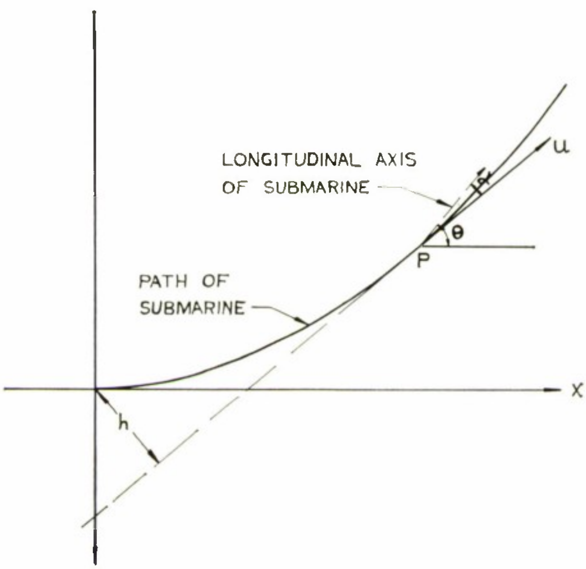


FIG. 16. Path of submarine following deflection of hydroplanes.

A Further Application of Asymptotic Response

Consider a submarine proceeding initially in a straight and level path, at some point in time the hydroplanes are deflected as quickly as possible to pre-determined angles and held in those positions. The track of the submarine is shown in Fig. 16.

The hydroplanes were moved over at point O, at some time t the submarine has reached P co-ordinates (x, z), it has pitch angle θ, the angle of incidence is α and the direction of motion at P is distant h from O. It is easily seen that:—

$$h = x\sin(\theta-\alpha) - z\cos(\theta-\alpha)$$

However once more it will be assumed that deviations are small enough to satisfy the assumption of the simplified approach, and thus:—

$$h = x(\theta-\alpha) - z$$

Furthermore $\alpha = \frac{w}{U}$ and $x = Ut$ and therefore:—

$$h = t(U\theta - w) - z$$

and since $\dot{z} = w - U\theta$

$$h = -t\dot{z} - z \qquad \dots (75)$$

Assume now that the initial application of the hydroplanes at O (*i.e.* t=O) is such that they produce no resultant force, merely a pitching moment. Using the equations introduced in Part IV, the following must thus be satisfied:—

$$\dot{w} + a_1 w = a_2\dot{\theta}$$
$$\ddot{\theta} + b_1\dot{\theta} + b_2\theta = b_3 w + b_4\delta \qquad \dots (76)$$

where $b_4\delta$ represents the pure pitching moment produced for simplicity by a single control surface deflected angle δ, in actual applications this term would represent the effect of forward and after hydroplanes combined.

Taking the Laplace transformation of equations (76) and solving:—

$$\frac{\theta(s)}{\delta(s)} = \frac{b_4(s+a_1)}{(s^3+(a_1+b_1)s^2+(a_1b_1-a_2b_3+b_2)s+a_1b_2)} \qquad \dots (77)$$

$$\frac{w(s)}{\delta(s)} = \frac{a_2b_4s}{(s^3+(a_1+b_1)s^2+(a_1b_1-a_2b_3+b_2)s+a_1b_2)} \qquad \dots (78)$$

and since $\dot{z} = w - U\theta$

$$\dot{z}(s) = w(s) - U\theta(s) = sz(s)$$

Furthermore if it is assumed that the hydroplanes are moved to their pre-determined angles instantaneously then:—

$$\delta(s) = \frac{\delta p}{s}$$

where δp is the pre-determined fixed angle.

Using the above equations, substitution gives:—

$$\dot{z}(s) = \frac{(a_2b_4s - Ub_4(s+a_1))\delta p}{s(s^3+(a_1+b_1)s^2+(a_1b_1-a_2b_3+b_2)s+a_1b_2)} = sz(s) \qquad \dots (79)$$

Now from equation (75):—

$$h = -t\dot{z} - z \text{ and thus } h(s) = -\frac{sdz(s)}{ds}$$

and by the final value theorem of the Laplace transformation theory:—

$$\lim_{t\to\infty} h = \lim_{s\to O}\left[-s^2\frac{dz(s)}{ds}\right] \qquad \ldots (80)$$

provided that if the denominator of the term in square brackets is a polynomial it has zero roots or the roots have negative real parts. Substitution gives:—

$$\lim_{t\to\infty} h = \lim_{s\to o}\left[-\frac{d}{ds}\left\{\frac{(a_2b_4s-Ub_4(s+a_1))\delta p}{(s^3+(a_1+b_1)s^2+(a_1b_1-a_2b_3+b_2)s+a_1b_2)}\right\}\right]$$

which simplifies to become:—

$$\lim_{t\to\infty} h = -\frac{b_4}{a_1b_2^2}\left\{a_2b_2-U(a_2b_3-a_1b_1)\right\}\delta p \qquad \ldots (81)$$

and the condition attached to equation (80) demands that the submarine is stable.

The coefficients in equation (81) were defined in Part IV as follows:—

$$a_1=-\frac{Z_w'U}{(m'-Z_{\dot{w}}')L}\quad;\quad a_2=\frac{(m'+Z_q')U}{(m'-Z_{\dot{w}}')}$$

$$b_1=-\frac{M_q'U}{(I_y'-M_{\dot{q}}')L}\quad;\quad b_2=\frac{m'g\overline{BG}}{(I_y'-M_{\dot{q}}')L^2}$$

$$b_3=\frac{M_w'U}{(I_y'-M_{\dot{q}}')L^2}\quad;\quad b_4=\frac{M'_\delta U^2}{(I_y'-M_{\dot{q}}')L^2}$$

and thus equation (81) becomes:—

$$\lim_{t\to\infty} h = \frac{M'_\delta LU^2}{Z_w'(m'g\overline{BG})^2}\left\{(m'+Z_q')m'g\overline{BG}- U^2\{(m'+Z_q')M_w'-Z_w'M_q'\}\right\}\delta p$$

From this equation it is seen that for a predetermined hydroplane angle δp, which produces a pure pitching moment, as $t\to\infty$ the distance h is a constant for a given speed of the submarine. Hence the path of the submarine must eventually become a straight line. Application of the final value theorem to equations (77) and (78) gives the ultimate values of θ and w which are:—

$$\theta=\frac{b_4}{b_2}\,\delta p\quad;\quad w=O \qquad \ldots (82)$$

The ultimate path of the submarine is thus a straight line at an angle θ to the horizontal (given by equation (82)), distance h from the point at which the hydroplanes were applied.

From equation (82) it is seen that:—

$$\delta p=\frac{m'g\overline{BG}}{M'_\delta U^2}\cdot\theta$$

and thus:—

$$\lim_{t\to\infty} h = \frac{L\theta}{Z_w'}\left\{(m'+Z_q')-\frac{U^2}{m'g\overline{BG}}(M_w'(m'+Z_q')-Z_w'M_q')\right\} \qquad \ldots (83)$$

This equation will be used in the description of how Z_q' and M_q' could be determined on full scale trials.

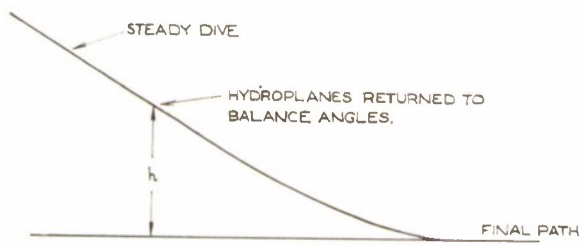


FIG. 17. Pull-out of submarine from steady dive.

Determination of Z_q' and M_q'

Consider now a submarine in a dive with bow-down pitch angle θ, and the hydroplanes held fixed at angles such that the incidence angle of the submarine is zero. If at some point the hydroplanes are returned as quickly as possible to their balance angles, provided the vessel was initially hydrostatically trimmed, its eventual path should be straight and level. This manoeuvre is illustrated in Fig. 17.

It is seen that this manoeuvre is exactly analagous to that analyzed in the preceding paragraph, and thus the depth increase from the point the hydroplanes are returned to balance angles to the final depth is given by equation (83) *viz*:—

$$h=\frac{L\theta}{Z_w'}\left\{(m'+Z_q')-\frac{U^2}{m'g\overline{BG}}(M_w'(m'+Z_q')-Z_w'M_q')\right\}$$

Now values of L, m′ and $\overline{BG}$ should be available, and M_w' and Z_w' could have been determined by the method described earlier. Values of θ, U, and h could be recorded on each manoeuvre of the above type, and hence if two manoeuvres were undertaken with different initial conditions it is possible to calculate values of Z_q' and M_q'. It is essential, of course, that this manoeuvre would have to be undertaken with great accuracy if the final result were to be reliable. Unfortunately the

manoeuvre demands an initial zero angle of incidence, and the angle of incidence is not particularly amenable to measurement. However apart from the determination of derivative values, this manoeuvre is of interest in that the pull out distance h is a measure of the ability of the vessel to pull-out from a dive without the use of control surfaces.

Yet Another Application of Asymptotic Response

If the motion of a submarine is adequately described by the simplified longitudinal equations, and the vessel is disturbed by a harmonically oscillating lift and pitching moment, ultimately the motion of the submarine in each degree of freedom should also be harmonic oscillations, but out of phase with the disturbance. Such an asymptotic motion would be described by the amplitude and phase of the oscillations in each degree of freedom. The detailed analysis of responses of this nature has been undertaken for servo-mechanisms and aircraft, and theoretically it is possible by similar analysis to obtain all the derivative values which describe the motion of a submarine.

In theory this method is certainly attractive, all the derivatives can be obtained, and the asymptotic response (if it can be achieved) in the vertical plane does not require excessive excursions in depth. The disadvantages are perhaps equally apparent, for instance, the disturbance can really only be applied by the hydroplanes, and these arc more likely to produce a trapezoidal disturbance rather than sinusoidal. This in itself may not be an unsurmountable difficulty provided the hydroplane movement can be controlled accurately, say by automatic control. It is unlikely that the time-honoured process of an officer issuing orders to a planesman would be accurate enough. Even if this problem were solved, however, analysis in the detail required by this method would require extremely accurate records, probably more accurate than those obtainable by practicable means.

Determination of the Damping Ratio

The methods described in the preceding paragraphs of this part were concerned with the determination of derivative values; of equal interest is a method for determining the damping ratio. It will be remembered that in Part IV the motion of a submarine in the vertical plane was compared to a second order servo-mechanism for which a damping coefficient of between 0·6 and 0·85 is satisfactory. It is possible to obtain the damping ratio on full-scale trials by analysis of the so-called meander manoeuvre[20].

To carry out the meander manoeuvre the hydroplanes are deflected to some pre-determined angle for a short interval of time and then returned to balance angles. The changes in depth and pitch angle are continuously recorded, and the subsequent analysis, as well as producing the damping ratio, also provides the time to damp to one-half amplitude, and the damped period of oscillation. Here again accuracy in carrying-out and recording the manoeuvre is essential.

PART XI. SUMMARY

Objectives Fulfilled

One of the reasons for embarking on a study of the stability and control of submarines was to develop a theory whereby the characteristics of a vessel could be determined in the design stage. At this stage a design can easily be modified if it is found that its predicted performance does not fulfil the desired requirements. Up to a point success has been achieved in this respect, since it has been shown that it is possible to predict the performance of a submarine before it is built, provided that some knowledge of the hydrodynamic forces is available. Unfortunately theoretical prediction of the hydrodynamic forces has not yet proved entirely adequate, and much of the basic data is obtained from model tests; unless, of course, a design is sufficiently similar to a previous design with known characteristics so that approximations to the basic data can be made. However, if reliable estimates of the hydrodynamic data are available it is possible to predict the performance characteristics of a submarine, and the following paragraphs are in the nature of a summary of the uses to which this information can be put.

A submarine is designed for particular operational requirements which the vessel should be able to undertake without undue risk to the operators. In the preceding pages a number of stability criteria and performance indices have been developen which could be used to indicate whether or not a particular design is satisfactory. One of these criteria—that of metacentric stability which ensures that the submarine remains in an upright position when at rest—was said to be a mandatory condition, satisfaction of the other criteria provides differing degrees of stabiliy and controllability, which may or may not be required. Obviously, in the stick fixed condition straight line stability is a desirable attribute, particularly in the vertical plane where because of the metacentric stability the submarine would then have directional stability. The stability criteria were given by relations (16) and (36). Stability should not, of course, be so great as to make control difficult, and by analogy with a servomechanism suitable values of the damping ratio were proposed. Another condition that should perhaps be mandatory

is that requiring a one-to-one correspondence between control surface movement and response of the submarine. Certainly this condition should be mandatory in the vertical plane where the operating depth is restricted, it is not quite so important in the horizontal plane, and in fact it has already been noted that boats have been known to exhibit a loop when subject to the spiral manoeuvre. However any loop must be of limited width, otherwise control will be rather difficult. Whether or not a particular design is likely to meet the performance requirements could also be assessed, by solving the equations of motion to determine the response to specific manoeuvres.

If the application of the theory in the above manner shows that all is well there should be no problems when the submarine is built. Should, however, the criteria be not satisfied, any modification to the design that is thought necessary will depend upon the experience and the " know-how " of the designer; since there is no one-to-one correspondence between structural and performance characteristics. To take a simple example, the addition of fin area in either plane at the stern affects all derivatives in that plane. Thus extra fin area in the plane of the hydroplanes (*e.g.* stabilizer fin) would provide a negative increment (say $-\delta x$) to Z_w' and approximately the following modification to the other derivatives:—

$$M_w' - \frac{\delta x l}{L}\ ;\quad Z_q' - \frac{\delta x l}{L}\ ;\quad M_q' - \delta x\left(\frac{l}{L}\right)^2$$

Similarly extra fin area in the plane of the rudder would provide a negative increment (again say $-\delta x$) to Y_v' and approximately the following modification to the other derivatives:—

$$N_v' + \frac{\delta x l}{L}\ ;\quad Y_r' + \frac{\delta x l}{L}\ ;\quad N_r' - \delta x\left(\frac{l}{L}\right)^2$$

where in each case the centre of pressure of the additional fin is assumed to be at distance l from the centre of gravity of the submarine. The magnitude of these increments would not necessarily be confirmed by model tests, but these theoretical values have been included to show that even a relatively simple structural modification does not alter the performance characteristics in a manner that is immediately apparent.

Following the assessment of the performance of a particular design it is also possible, if required, to study the design of suitable control systems in order that full advantage can be taken of the improved manoeuvrability of the modern submarine. Computer simulation of the submarine motion, which of course demands initial knowledge of the equations, is ideally suited to this application. Simulated control systems can be linked to the simulated submarine and performances compared; in fact, in the later stages of the design of a control system the actual hardware can be coupled via suitable transducers to the computer simulation of the submarine itself. Automatic controls have been successfully designed and evaluated using these techniques. However, even the best automatic control could fail, and thus manual control should also be assessed particularly as the task of the human operator becomes increasingly difficult as development proceeds. It is clearly a simple matter to couple manual controls to a simulation, but the more important consideration is in the provision of a suitable display system for the operator. Most operators would find control difficult if they were provided with no more than the usual plethora of instruments recording on separate gauges the depth, pitch angle, heading angle, rudder angle, hydroplane angles, *etc.* " Quickened " display systems have already been mentioned, systems which reduce the presentation of information to the minimum number of instruments and also reduce the amount of anticipation required from the operator, and systems of this type have been evaluated by simulation.

The evaluation of automatic controls is perhaps easier in some respects than the evaluation of manual control, in particular the human operator is susceptible to his environment to a much greater degree. Hence, if possible, for investigations involving human operators the actual motions, and the environment of the control room (including noise) should be reproduced. The production of such a simulator is naturally a major undertaking, but a number have been constructed which are exact replicas of submarine control rooms, which can also be pitched and rolled. A computer is used to solve the equations of motion in real time, the inputs to the equations being simulated external disturbances, or control column movements by the operator; the outputs of the equations (*i.e.* the motion of the submarine) are used to drive a mechanism that pitches and rolls the cabin in the appropriate manner. The equations of motion required for such a device are similar to those given in this note, with a few additional terms to represent taking on or blowing out of ballast water, *etc.* Simulators of this type are of course ideal for the training of operators before going to sea.

The above paragraphs of this section have been concerned with the use of theoretical methods for the evaluation of a design and its equipment. A further use of the theory is the prediction of the areas of safe operation taking into account any limitations of the equipment. The deeply submerged submarine is subject to enormous pressure, and indeed at some depth the hull will collapse; this collapse depth is dependent upon the materials of construction and the manufacturing techniques.

Obviously it is vitally important that any submarine should not approach its collapse depth too closely, even in the event of an emergency. The mode of operation of a submarine is, of course, for the submariner to decide, but at least guidance can be given on the effectiveness of the recovery procedures in the event of an emergency, and also some indication given of the limitations of speed, depth, pitch angle, and hydroplane angles which, if observed, would ensure that the submarine was at any time in a position from which recovery is possible. Such information can be obtained by solving the equations of motion with simulations of the emergencies and recovery procedures.

Problems for Further Study

Equations of motion of the type described in this contribution are reasonably realistic in the representation of the motion of a submarine although there are shortcomings, particularly now that motions are such that many of the hydrodynamic forces must be highly non-linear. Certainly there would appear to be room for improvement in the mathematical simulation of tight turns, including the prediction of snap roll angles, and also in the simulation of emergencies, and the recovery procedures. In view of the difficulties experienced in the theoretical determination of the hydrodynamic forces on a submarine it seems likely that solution of the above problems will have to rely on refined experimental techniques. However, where simplified equations are applicable it would be very advantageous to be able to calculate reliable derivative values without the need for model experiments. On the face of it this should not be an intractable problem for the deeply submerged submarine, greater difficulties arise in the consideration of near surface operations.

Future Development

The modern submarine is probably in most cases sufficiently manoeuvrable to meet all its requirements, and in many cases its full potential is never exercised. The greatest restriction in submarine operation is that imposed by the collapse depth, and in this respect there is scope for future development, if there is any requirement for it. The discussion of the manufacturing techniques and materials required to increase collapse depth is outside the scope of this note, but greater operating depths would affect some of the problems with which preceding chapters have been concerned. In particular, this applies to the consideration of emergencies and recovery procedures, which would require re-investigation for greater operating depths, since it has already been indicated that there is no really successful recovery procedure in the direst emergency even at present operating depths. One thing apparent from the investigation of the recovery procedures was the extreme importance of the immediate appreciation of any emergency, and the equally immediate initiation of the available recovery procedures. This factor can only be of even more importance at greater operating depths and alarm systems should cover all possible sources of emergencies. Conversely it is from a consideration of emergencies that a requirement for greater operating depth could arise. Certainly if a submarine did not collapse in the event of a failure it could sit on the sea bed while undertaking repairs or awaiting rescue, provided, of course, that suitable rescue vessels had been developed concurrently.

Control of the submarine should not present any more major problems; there is sufficient knowledge available with respect to suitable automatic controls, and effective display systems for manual operation. However it is obvious that at low speeds in regions where there are noticeable effects due to surface disturbance it is difficult to maintain depth accurately using hydroplanes alone, since at very low speeds the hydroplanes are relatively ineffective (because the force generated by their displacement is dependent upon the square of the velocity). In fact were it not largely for low speed considerations the forward hydroplanes may well have been dispensed with in the modern submarine. As was noted in Part IV the forward hydroplanes do not suffer reversal at low speeds, and over a limited speed range near the reversal speed of the after hydroplanes the forward hydroplanes are more effective in depth changing. At high speeds, however, the effect of the forward hydroplanes is negligible. Hence, for efficient depth control at very low speeds (if required) it is necessary to have some additional method of control, high speed transference of ballast water being the most obvious solution.

A number of undesirable effects in the motion of a submarine are due in no small measure to the presence of the rather large bridge fin. Certainly the bridge fin is a major contributory factor to the rolling that occurs when rudder is applied, although removal of the bridge fin does not entirely eliminate roll. More effective roll control is perhaps a possibility, although again there is a problem at low speeds when hydrodynamic controls are less efficient. Furthermore it is clear from the asymmetry of the bridge fin that it would cause a submarine to roll when coming to the surface more or less vertically, under the effect of buoyancy caused by blowing ballast. Clearly there is a case for reduction in the relative size of the bridge fin, although this invokes problems in the housing of periscopes and other equipment.

Apart from a few oceanographic vehicles which can hardly be described as submarines in this context, ships that have been built to date have been specifically for military applications. It is not inconceivable that in the future cargo submarines may make their appearance. There have been a number of papers on the subject of cargo submarines showing that, apart from the possibility of blockade running, in certain instances the cargo submarine could be an economic proposition (see for instance Reference [27]. The most suitable cargoes are those of high density and of such consistency that they can be loaded and unloaded through relatively small hatches. Broken mineral ores, coal, and oil fall into these categories. Economy becomes a consideration if quick turn round can be achieved and speeds of the order of 30 knots maintained in transit. A particular application that springs to mind is the ability of the submarine to travel beneath the ice, and hence provide all the year round service to ports which would otherwise be closed in winter without the extensive and expensive use of icebreakers. There are, of course, a number of logistic problems which would require solution before such a project could become a reality, but at least sufficient is now known about the stability and control of underwater vehicles to ensure that there are no problems in this respect.

References

(21) "Equations of motion of a Submerged Body with Varying Mass", A. Strumpf. *Davidson Laboratory Report* 771.

(22) "Analytical Determination of a Loop Associated with Directionally Unstable Ships." *D.T.M.B. Report* 1274.

(23) "Preliminary Analysis of Manual and Automatic Steering of a Directionally Unstable Model which Exhibits a Loop." *D.T.M.B. Report* 1280.

(24) "The Forces on a submerged Body Moving under Waves." Sir T. H. Havelock. *Trans. R.I.N.A.* (April 1954).

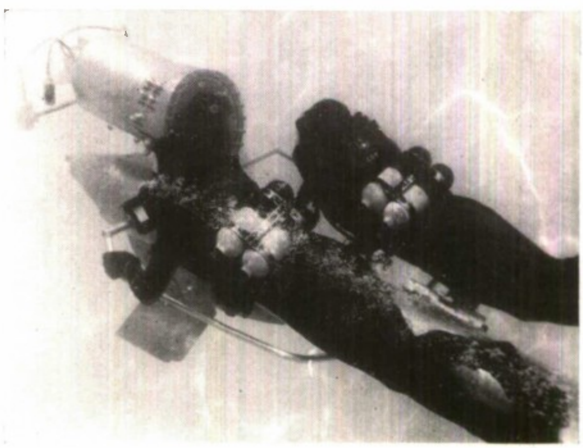
(25) "On the Motions of Ships in Confused Seas." M. St. Denis and W. J. Pierson. *Trans. S.N.A.M.E.* (1953).

(26) "The Influence of Ship Motions of Different Wave Spectra and of Ship Length." J. A. Ewing and G. J. Goodrich. *Trans. R.I.N.A.* (1966).

(27) "The Submarine Ore Carrier." P. R. Crewe and D. J. Hardy. *Trans. R.I.N.A.* (1962).

TWO-MAN WET UNDERWATER VEHICLE

The ability of swimmers to perform tasks underwater is very largely dependent on the equipment with which they are provided. When swimmers have to travel considerable distances underwater either in carrying out their duties or between the point at which they enter the water and that where they are required to operate, then their activities are largely limited by their physical endurance and breathing equipment. These limitations can be reduced if the swimmers can be provided with some means of underwater mobility which will enable them to move at higher speeds than can normally be achieved by an unaided swimmer and with the minimum of fatigue.



To this end, a two-man wet underwater vehicle has been designed and produced by Admiralty Materials Laboratory. The two underwater swimmers are accommodated lying on either side of and above the main hull. The lefthand swimmer controls the vehicle by the use of a foot operated rudder bar and a hand control to the linked forward and after hydroplanes. A comprehensive range of instruments is displayed in the central pod to both swimmers to enable them to navigate over short distances (*e.g.* compass, log, speed indicator and depth gauge) and to monitor the performance of the vehicle (*e.g.* voltmeter, ammeter and tachometer). The vehicle is powered by a silver zinc battery operating through a d.c. motor and reduction gearing to an adjustable pitch propeller. A speed in excess of three knots can be achieved which is the maximum which an unprotected swimmer can withstand on an exposed wet vehicle.

Negotiations are at present in hand with the National Research Development Corporation to assess the potential of this vehicle in the field of civil underwater operations with a view to commercial exploitation of the design.

PSEUDO-LOGARITHMIC SCALES FOR ION CHAMBER RADIATION MEASURING INSTRUMENTS

B. W. Soole, A.R.C.S., B.Sc., D.I.C., Ph.D., A.Inst.P., R.N.S.S. and W. F. Jager, C.Eng., M.I.E.R.E., R.N.S.S.
Admiralty Research Laboratory

SUMMARY

The measurement of a wide range of radiation exposure-rate by a portable instrument may conveniently be done by a combination of an air-filled ion chamber with air-equivalent walls and an electrometer valve operated with its grid a volt or two negative when, provided that the ion current flows into the grid, the meter indication will be closely proportional to the logarithm of the exposure-rate over many decades.

To provide a definite meter indication in the absence of radiation a small standing current must be supplied to the electrometer. This will reduce the time of response and, if sufficiently accurately defined, may also be used for calibration.

It has been found that sufficiently precise currents may be more satisfactorily supplied through a high grid resistor than by a small radioactive source, but the presence of this resistor, by providing an alternative path for the ionization current modifies the logarithmic response. The resulting pseudo-logarithmic scale, however, may be derived when the static grid characteristics of the electrometer valve are known.

Such characteristics have been determined for a Mullard ME 1401 triode electrometer and examples of derived pseudo-logarithmic scales are given. With appropriate interpretation they may also be used for the measurement of small currents of any other origin.

Introduction

Ionization currents proportional to a wide range of radiation exposure-rates are conveniently amplified by feeding them to the control grid of an electrometer valve operated with a retarding field between cathode and grid when, as a result of the Maxwellian distribution of velocities among the electrons thermionically emitted from the cathode

$$e_g = \frac{T}{5035} \log \frac{i_g}{i_{go}}, \qquad (1)$$

where e_g is the (negative) potential of the grid with respect to the cathode in volts,
i_g is the corresponding current flowing into the grid,
i_{go} is the value of i_g when e_g is zero,
and T is the absolute temperature of the cathode,

so that as shown by Chao[1] for a cathode temperature of 1,000°K, for example, e_g increases by 198mV in negative magnitude (producing corresponding changes in the anode circuit) for every decade decrease of i_g relative to i_{go}.

If an uncertain meter indication in the absence of radiation is to be avoided with an instrument having such a logarithmic response, it will be necessary to provide a small standing current to the electrometer grid. Such a current will also reduce the response time of the instrument and, if defined with sufficient accuracy, may be used for calibration.

Although Taylor[2] showed that an unvarying current of a suitable magnitude may easily be produced by a small beta-active source within the ion chamber, the size of such a current is not only difficult to adjust in the first instance but, it has been found, is very dependent in practice upon the thickness of the protective layer

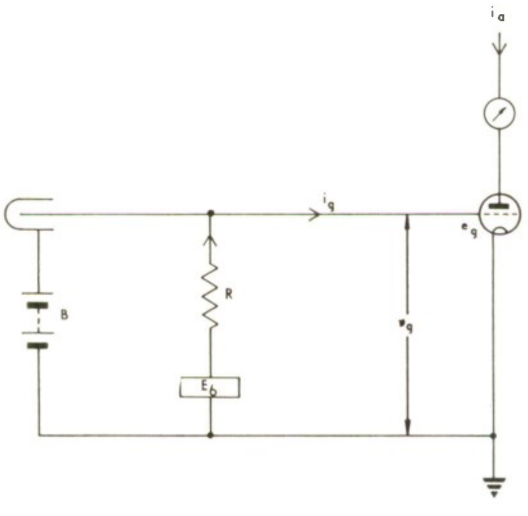


FIG. 1. The circuit.

covering the radio-active deposit, so that reliable manufacture with the necessary accuracy is difficult. Consideration has therefore been given to the provision of a standing current by means of a leak through an accurate high resistor R as shown for a triode in Fig. 1, where E_b represents a source of variable voltage by which the leakage current may initially be adjusted to the correct value. This procedure has been adopted by Perry and Washtell[3], Chao[1] and Luskow[4].

The resistor provides however, an alternative path for the ion chamber current which may be ignored only so long as R is large compared with the grid-cathode resistance of the valve. If this is not so, then an appreciable fraction of the ion current will by-pass the electrometer and the grid potential will no longer be proportional to the logarithm of the ion current, but to the logarithm of only a part and possibly of a variable part, of it.

Thus prediction of the relationship between ion current and meter indication for a given value of R can only be made when the grid-cathode resistance of the valve and its variation, if any, with grid current i_g is known. As shown by Morant[5], however, the operation of this circuit is complicated by the generation within the valve of the negative e.m.f. e_g which must be added algebraically to the potential drop resulting from the passage of grid current through the grid-cathode space to give the measurable grid-cathode potential v_g. It will be shown however that if the relationship between v_g and i_g is known, then the loss of ion current through the grid resistor may be easily calculated from a knowledge of R and E_b without a separate knowledge of either e_g or of the grid-cathode resistance.

If the relationship between v_g and the anode current i_a is also known, then the required pseudo-logarithmic relationship between the ion chamber current and the anode-current i_a, to which in this example the instrument meter indication is taken to be proportional, may be derived.

Theoretical Considerations

Assuming all potentials to be measured with respect to the earthed side of the filament cathode (Fig. 1), and regarding conventional current flow from the grid to cathode within the valve as positive, then in the absence of any radiation-produced current from the ion chamber,

$$i_g = \frac{E_b - e_g}{R + r_g}, \tag{2}$$

where r_g is the true (positive) grid-cathode resistance of the valve under operating conditions. (It is assumed that the insulation resistance of the ion chamber is infinite and that therefore, provided the e.m.f. of the battery B is sufficient to produce saturation it does not otherwise enter into the operation of the circuit.) Thus there will be no current flow when E_b and e_g are equal both in magnitude and in (negative) sign.

When positive current does flow, namely when E_b is less negative than e_g, zero or positive, there will be a potential drop across the resistances in the circuit, so that the potential of the grid, v_g, will not then be equal to e_g.

We have, referring to the leakage resistor

$$v_g = E_b - i_g R \tag{3}$$

and, to the valve

$$v_g = e_g + i_g r_g. \tag{4}$$

From either (3) or (4) and (2) we have

$$v_g = \frac{E_b\left(\frac{r_g}{R}\right) + e_g}{1 + \left(\frac{r_g}{R}\right)}, \tag{5}$$

so that only when r_g is negligible compared with R will v_g be equal to e_g; otherwise, when E_b is zero, v_g will, like e_g be negative, but smaller in magnitude. When E_b is not zero, the value of v_g can only be stated when E_b is known as well as R, r_g and e_g. Since both e_g and r_g will, in general, be functions of i_g, then by (4) so will v_g. So long as e_g is negative and there is a linear relation between e_g and log i_g (which implies that i_g remains positive) we may use (1) with (4) to give

$$v_g = K \log i_g + C \tag{6}$$

where $K = \dfrac{T}{5035}$

and $C = i_g r_g - \dfrac{T}{5035} \log i_{go}.$

Thus an experimentally observed linear relation between v_g and $\log i_g$ not only enables an effective absolute temperature T of the cathode to be determined, but shows that, in order to maintain the observed constancy of C, the true grid-cathode resistance r_g must vary inversely as i_g.

An effective resistance r_{eff} between grid and cathode may be defined by the relation

$$r_{eff} = \frac{v_g}{i_g} \qquad (7)$$

which, by (4) becomes

$$r_{eff} = r_g + \frac{e_g}{i_g}$$

Thus the effective resistance is equal to the true positive resistance plus a term arising from the existence of the e.m.f. generated within the electrometer valve. When conventional current flows from grid to cathode within the valve, as considered here, this second term will be negative. Both terms and therefore the effective resistance will be functions of the grid current i_g.

From (2), for no current to flow, either R must be infinite, or E_b equal in magnitude and sign to e_g. In the latter case, from (3) v_g must then also be negative and equal in magnitude to e_g. It follows from (7) that r_{eff} then has an infinite negative value. As current begins to flow into the grid, v_g is observed to decrease in negative magnitude. This means by (7), that i_g being positive, r_{eff} also decreases in negative magnitude until, when v_g becomes zero, it also becomes zero. With a further increase of i_g, both v_g and r_{eff} will become and remain positive.

Although considerable data supporting the linear relationship between v_g and $\log i_g$ exist for thermionic diodes and diode-connected multigrid valves (Meagher and Bentley[6], Wade[7], Cox[8], Sikorsky[9]), surprisingly little reliable quantitative experimental evidence has been published relating to a triode or triode-connected tetrode or pentode. Chao shows a linear relation for values of what is stated to be i_g extending from 10^{-13} A to 10^{-10} A for the triode connected Raytheon electrometer tetrode CK 5889 operated with an anode potential of 5·2 volts. No experimental details are given although it appears that the small currents were obtained from an ion chamber, but the same symbol is used for ion current as for grid current in spite of the presence of a grid resistor. Bishop[10] shows a linear relation extending from 2×10^{-14} A to 10^{-7} A also for the CK 5889 but operated with feedback to the screen grid to keep the anode current constant at 10μA as recommended by Cox[8]. The relation however follows from an assumption of the constancy of C and two (only) experimental points to determine the position of the line.

The slopes of the lines shown by Chao and by Bishop correspond to values of K of 265 and 257 mV per decade of i_g respectively and thus to an effective filament temperature appreciably higher than 1,000°K.

The importance of knowing the relationship between v_g and i_g arises from the fact that the relationship between the ion current I and i_g may then be determined without the necessity of knowing also the values of e_g and r_g.

Thus if, in Fig. 1 a current I flows from the ion chamber, then the current passing to the grid through R becomes I_R where

$$i_g = I_R + I. \qquad (8)$$

Also, then $$v_g = E_b - I_R R \qquad (9)$$

hence $$I = i_g - \frac{E_b - v_g}{R}, \qquad (10)$$

and $$I_R = \frac{E_b - v_g}{R}. \qquad (11)$$

The 'Ideal' Pseudo-Logarithmic Scale

In practice to avoid loss of accuracy at the lower end of the measurement range, E_b and R should be chosen to give, in the absence of any ion current, a standing current I_o that is not large compared with the smallest ion current to be measured. However, the difficulties of defining and maintaining the value of I_o with sufficient precision for it to be a useful calibrating current increase the smaller it is. A suitable compromise is to make I_o exactly equal to the smallest value of I that it is required to measure, a proposal that has the added advantage of providing a simple definition of the scale.

Thus, if we assume that it is required to measure n decades of exposure-rate from D to 10^nD R/h and if the ion chamber sensitivity is S amp per R/h then the corresponding range of values of I will be from SD to 10^nSD.

If we therefore could make I_o equal to SD in such a way as to have no effect upon the passage of all the ion current into the electrometer grid, that is in such a way as to ensure that $\frac{E_b - v_g}{R}$ (which, as I_R, is equal to I_o when I=0) remained constant at SD, and we had an accurately logarithmic relation between grid current (which would then be equal to $I + I_o$) and meter indication, then the general relationship between the inscription on the scale (Q R/h) and the graduation (L) on the conventional logarithmic scale against which the inscription is made would be given by

$$Q = D.L - D$$

where $$1 \leqslant L \leqslant 10^n.$$

Examples of this relationship are shown in Table I.

TABLE I

Logarithmic Graduation	*Inscription (R/h)*
1	O
2	D
5	4D
10	9D
11	10D
..	..
10^n+1	10^nD

A scale marked in this way will be termed an 'ideal' pseudo-logarithmic scale, departures from a true logarithmic relationship between ion current and meter indication occurring only because of the presence in the grid current of a constant component (the standing current, I_o) in addition to the ion current I, the relationship between grid current and meter indication being assumed to be logarithmic. Such an ideal scale would result with the same assumption, if the standing current were produced by a small beta-active source.

Non-ideal Pseudo-Logarithmic Scales

In practice, the assumption that the term $\frac{E_b - v_g}{R}$ (that is, I_R) is constant with variation of I will not be valid, since a proportion of the ion current will by-pass the electrometer valve through the resistor R in opposition to the initial standing value I_o, that is SD, of I_R, (and at a sufficiently high value of I will reverse the direction of the net current through R). Moreover the proportion of I passing through R will not be constant in view of the variability of v_g with i_g.

Thus the practical pseudo-logarithmic scale will depart from the logarithmic form not only because of the presence of a priming current I_o as a constant component of the grid current, as does the ideal pseudo-logarithmic scale, but additionally because of a variable loss of ion current through the grid resistor.

Futhermore there is not necessarily an accurate logarithmic relation between grid current and meter indication even if there is between grid current and grid voltage. If, as in the case considered, the meter indication is accurately proportional to the electrometer anode current, the assumption requires that grid voltage and anode current be linearly related. This is not so, the relation for a triode being

$$\delta i_a = \frac{\mu \delta v_g}{r_a + R_L} \tag{12}$$

where r_a is the anode slope-resistance and R_L is the anode load resistor.

Although the amplification factor μ is constant as i_a varies, r_a decreases as $i_a^{-\frac{1}{3}}$, so that the anode current increases more rapidly as the grid voltage increases (or decreases in negative magnitude). This, of course may be reduced to any desired extent by increasing the anode load resistor R_L, provided that the resulting anode current is large enough, with amplification if necessary, to operate the indicating meter.

Thus to determine the practical form of the pseudo-logarithmic scale it is necessary, firstly, to know the variation of v_g with i_g so that i_g may be evaluated as a function of I (10) for given values of E_b and R. These will have been chosen to give a standing grid current I_o, in the absence of any ion current, equal to SD.

We have from (2) and (4)

$$E_b = I_o R + v_g \tag{13}$$

where I_o is written for a value of i_g when I = O.

So, if I_o is chosen to be equal to SD, then when a value of R has been selected, E_b may be calculated when v_g is known as a function of i_g, and thus in particular for a value of i_g equal to SD.

To determine the meter indication assumed to be directly proportional to the anode current i_a, it will be necessary to determine the latter also as a function of i_g. If this and the measurements of the v_g versus i_g characteristics are made at several constant anode voltages v_a, that is, without any appreciable load resistor in circuit, then the results may be used to derive similar relationships with an anode load resistor by the use of load lines in the usual way.

Experimental Procedure

Preliminary experiments were performed with the circuit arrangement shown in which, with a carefully adjusted value of I_o flowing to the grid through the known high resistor R (10^{12} ohms), accurate predetermined values of I were produced in the ion chamber by a suitably disposed radioactive source. The resulting values of current I_R flowing through R were measured using a vibrating reed electrometer, (Ekco, Type N616B) and values of v_g were calculated from (9). A similar method appears to have been used by Chao.

More consistent results over a wider range of i_g however were obtained with a greater practical convenience by taking advantage of the use of negative feed-back in the vibrating reed electrometer when connected to measure 'ion chamber' current. Under these conditions, when a source of potential E_b was applied to the grid of the electrometer under test (Mullard ME 1401) through the input resistor of the vibrating reed electrometer, the effective value of this resistance in the grid circuit of the ME 1401, because of

feed-back, was rendered negligible compared with the valve's internal resistance between grid and cathode. That this was so was verified on each range of measurement by momentarily shorting this input resistor, when no resultant change was ever observable in the anode current of the ME 1401.

With this arrangement, it follows from (9) with R zero that $v_g = E_b$. Thus by directly measuring the potential required to produce the measured grid current the relationship between grid potential v_g and grid current i_g with the valve operating with a constant filament current and at a known anode potential was determined.

Throughout the series of measurements the electrometer was kept enclosed in a metal can so that spurious photo-currents arising from external illumination were eliminated. Anode and grid currents were fed through P.T.F.E. insulated connectors and short lengths of polythene-insulated coaxial cable. A Solartron Transistor Power Unit Type AS140 supplied filament current at an uninterrupted 13mA$\pm$0·05%, and a similar AS140 provided the anode supply potential through a microammeter of negligible load. The source of potential E_b was provided from a regulated supply and standardized potentiometrically against a standard cell.

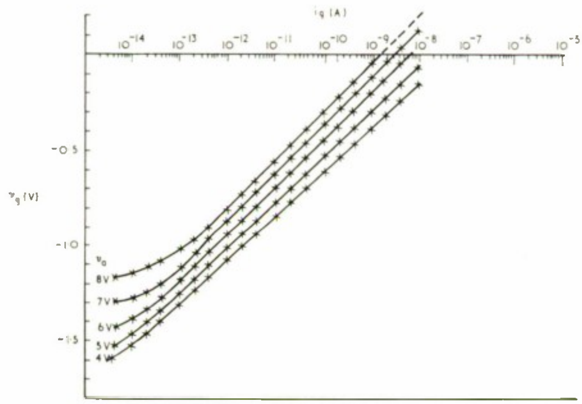


FIG. 2. Observed grid current and potentials of the ME 1401 triode.

Results

The experimentally determined variations of v_g, r_{eff} and i_a with i_g for several anode potentials are shown in Figs. 2, 3 and 4 respectively.

The slope K of the v_g versus log i_g characteristic increases slightly with anode potential over its linear range ($i_g = c.10^{-13} - 10^{-8}$A or more). Values are given in Table II for comparison with the previously quoted values given by Chao and Bishop for the CK 5889. Agreement is seen to be close.

TABLE II

v_a	K
4V	233 mV
5	241
6	249
7	255
8	255

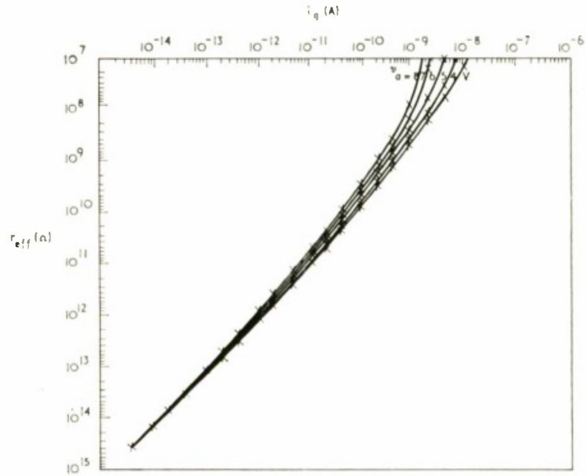


FIG. 3. Grid currents and effective grid-cathode resistance.

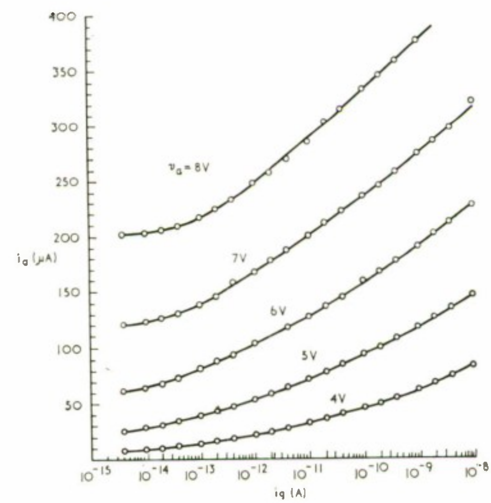


FIG. 4. Current transfer characteristics.

Derivation of Practical Pseudo-Logarithmic Scales

In all cases a value of 6·00 $\times$ 10^{-13}A has been taken for SD corresponding, for example, to the exposure of an air-filled ion chamber with air-

equivalent walls and a volume of about 60 cm^3 to an exposure-rate of 0·1 R/h ($S = 6{\cdot}0 \times 10^{-12}$A per R/h).

For this value of standing current I_o, initially constituting the grid current i_g, values of v_g have been read from each of the curves of Fig. 2. The battery voltages E_b required to provide this current in the absence of any ion current I through various values of high resistor derived from (13) are shown in Table III.

TABLE III

Values of E_b (volts) to give $I_o = 6{\cdot}00 \times 10^{-13}$A (from 13)

R	v_a=4	5	6	7	8
10^{10}	−1·124	−1·061	−0·986	−0·922	−0·861
10^{11}	−1·070	−1·007	−0·932	−0·868	−0·807
10^{12}	−0·530	−0·467	−0·392	−0·328	−0·267
10^{13}	4·870	4·933	5·008	5·072	5·133
10^{14}	58·870	58·933	59·008	59·072	59·133

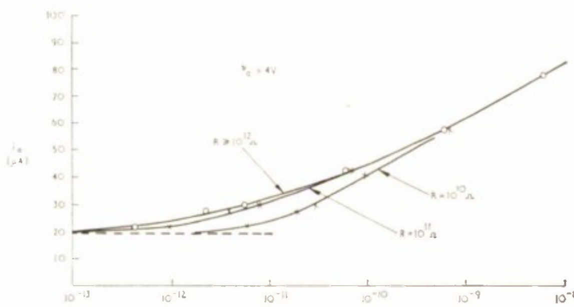


FIG. 5. Example of anode current variation with ion chamber current with a standing current I_o of $6{\cdot}00 \times 10^{-13}$A.

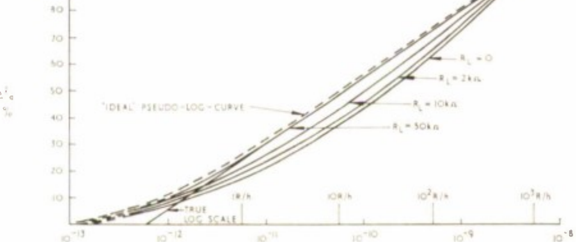


FIG. 6. Pseudo-logarithmic scales.

These values of E_b with the corresponding values of R have been substituted in (10) together with pairs of values of v_g and i_g from Fig. 2 to determine corresponding values of the ion current I. The relationship between these and values of i_a corresponding to the same values of i_g (Fig. 4) are shown for an anode potential of 4V, in Fig. 5.

It will be seen that a reduction of the grid leakage resistor below 10^{12} ohms allows a high and increasing proportion of the smaller ion currents to by-pass the electrometer, so that the response to currents of $10^{-13} - 10^{-10}$A is seriously reduced, and this is found also to be true of the results obtained with the other anode voltages.

Although resistors of more than 10^{12} ohms reduce the proportion of an ion current that by-passes the valve still further, the extra reduction is too small to be distinguished in the figure, and, within the range of the variables indicated, the effect of such resistors may be taken without appreciable error, to be equal to that of a resistor of 10^{12} ohms and again this is found to be true with all the other anode voltages.

In practice, the presence of an anode load of resistance R_L will cause the anode potential to fall with increase of anode current and the behaviour of the circuit must be determined by drawing the appropriate load line on an anode voltage-current plot in the usual way. As an example, i_a versus v_a curves were drawn for I=0, 6×10^{-13}A and four ten-fold multiples of 6×10^{-13}A for values of $R \geqslant 10^{12}\Omega$ using data from the upper curves of Fig. 5 and similar figures with v_a = 5, 6, 7 and 8V. Results derived from three load lines corresponding to R_L values of 2, 10 and 50kΩ drawn through the point ($I = 6 \times 10^{-9}$A, v_a=4V, i_a=78·0 μA) are shown in Fig. 6, where 100%Δi_a corresponds to the increase upon exposure to 10^3 R/h ($I = 6 \times 10^{-9}$A) of the anode current above the level with only the grid standing current of $6{\cdot}0 \times 10^{-13}$A (58·2, 55·6, 45·8 and 22·5μA with R_L=0, 2, 10 and 50 kΩ respectively). The corresponding indications of an 'ideal' pseudo-logarithmic scale (Table I) and an accurately logarithmic scale (with a zero reading for 0·1 R/h and of minus infinity for zero radiation) are shown for comparison.

It will be seen that, as expected, an increase in the value of the load resistor reduces the relative insensitivity of the electrometer to the smaller ion currents. The effect is progressive, but by comparison with the ' ideal ' scale which makes no allowance for any loss of ion current through the resistor it can be seen that there is little room for improvement in log-linearity by the use of a load resistor greater than about 50,000 ohms. This is found also to be true with anode voltages up to 6V (at higher values of v_a, i_a rises above the safe limit of 250μA when $I = 6 \times 10^{-9}$ A).

Intercomparison of the results obtained with the various values of v_a shows that with the highest value of load resistor the shape of the scale is less dependent upon the anode potential. When operated at the lower anode voltages the responses are more sensitive to the value of the load resistor. At the higher anode potentials however, the scale indications for the higher value of load resistor show an upward deviation at the centre of the range slightly beyond the value of the 'ideal' pseudo-logarithmic scale. This is the result of a simultaneous increase in slope and in separation of the i_a versus v_a curves as the anode potential is increased.

Conclusions

It has been shown that when a small standing current is supplied by a source of e.m.f. acting through a high resistor to the grid of an ME 1401 triode electrometer valve also connected to an ion chamber so that when the electrometer is operated in the logarithmic mode it can easily be made to reproduce any reasonable indication in the absence of radiation, the response to ion current departs from the truly logarithmic over the lower decades not only because the standing current is necessarily then an appreciable part of the grid current, but because the increase in the effective internal resistance between grid and cathode of the valve as the grid current is reduced causes an increasing proportion of the ion current to leak through the high resistor. It is shown as an example, that when the smallest ion currents to be measured are about $6{\cdot}0 \times 10^{-13}$A, the leakage may be reduced to the maximum practicable degree by a high resistor value of 10^{12} ohms or more. The relative sensitivity of the electrometer to the smaller ion currents may be increased by the insertion of an anode load resistor, though there is little advantage in increasing this above 50,000Ω with an anode potential of 6 volts or less.

Relationships between anode current and ion current for other values of standing current may be derived in the same way from the data presented.

Pseudo-logarithmic scales may be similarly derived for triode-connected electrometer tetrodes and pentodes, but when these valves are operated with feed-back to the screen holding the anode current constant (Cox[8], Cox and Walker[11], Perry and Washtell[3], Bishop[10]), then a knowledge of the variation of screen potential (at constant anode current) must replace that of the anode current.

Acknowledgement

It is a pleasure to record our appreciation of the assistance of Mr. D. C. Fricker* in the making of the many observations.

References

(1) S. K. Chao, "Logarithmic Characteristic of Triode Electrometer Circuits", *Review of Scientific Instruments*, **30**, No. 12, pp. 1087-1092, December 1959.

(2) D. Taylor, "Radiac Instrumentation", *Journal of Scientific Instruments*, **9**, pp. 315-321, October 1952.

(3) K. E. G. Perry and C. C. H. Washtell, "A Simple Wide-range Gamma Dose-rate Meter", *Nuclear Power*, **1**, No. 1, pp. 17-19, 28, May 1956.

(4) A. A. Luskow, "Gamma Radiation Monitor, Type TF 1299", *Marconi Instruments*, **8**, No. 2, pp. 36-39, June 1961.

(5) M. J. Morant, "The Application of the Electrometer Valve to Charge Measurement", *Journal of Scientific Instruments*, **31**, pp. 391-395, November 1954.

(6) R. E. Meagher and E. P. Bentley, "Vacuum Tube Circuit to Measure the Logarithm of a Direct Current", *Review of Scientific Instruments*, **10**, pp. 336-339, November 1939.

(7) E. J. Wade, "Instruments Used with Experimental Reactors", *Convention Record of the Institution of Radio Engineers, Part 9, Medical and Nuclear Electronics*, pp. 79-82, 1954.

(8) R. J. Cox, "Automatic Start-up of Nuclear Reactors", *Institution of Radio Engineers Transactions on Nuclear Science*, **NS-3**, No. 1, pp. 15-20, February 1956.

(9) E. Sikorsky, "An Evaluation of Vacuum Tubes for Log N Amplifiers", *Institution of Electronic and Electrical Engineers Transactions on Nuclear Science*, **NS-10**, No. 1, pp. 42-51, January 1963.

(10) S. R. Bishop, "A Logarithmic Current-to-Voltage Amplifier with High Sensitivity, Stability and Dynamic Range, Suitable for Field Application", *Institution of Electronic and Electrical Engineers Transactions on Nuclear Science*, **NS-13**, No. 1, pp. 602-610, February 1966.

(11) R. J. Cox and J. Walker, "The Control of Nuclear Reactors", *Proceedings of the Institution of Electrical Engineers*, **103B**, pp. 577-589 and 607-615, March 1956.

* Now at Bristol University.

'OLMEDA' and 'BRITANNIA' on passage to Gibraltar, April 1968

RFA *Olmeda*, together with her sister ships RFA *Olwen* and *Olna*, is the largest and fastest vessel to join the Royal Fleet Auxiliary Service and as a fast replenishment tanker, has become an important part of the Royal Navy's "life-line at sea". She was designed to replenish fighting ships with Fuel and Stores while steaming at speed.

The ship was built and commissioned October 1965 as RFA *Oleander*.

Her name was changed to RFA *Olmeda* in October 1967 because of confusion arising with the frigate, HMS *Leander*. She is the first ship in the Royal Fleet Auxiliary Service to bear the name *Olmeda*.

With a length of 648 feet and a displacement of 33,280 tons, the ship has sophisticated machinery systems installed, equipped with modern forms of automatic and remote control. All manoeuvring is under direct control from the bridge, and centralised remote control of the cargo handling gear is provided. An automatic data logging system is installed in the main machinery control room. She has a horse power in excess of 26,000.

A feature of the ship is the helicopter landing deck which enables her to carry and operate three helicopters and to fuel helicopters carried by other ships. The aircraft are used for the transfer of light stores between ships and for training purposes.

Supplying the Fleet is a task as old as the Royal Navy itself. Ships laden with stores and known as "pinks" accompanied the squadrons of Drake and Frobisher to distant waters. Supplies of beer and bullocks were carried from Plymouth to Brest during Hawke's siege of 1759. During Nelson's Mediterranean campaigns, stores were brought to his ships by sea from Gibraltar. It was not, however, until steam replaced sail as a means of propulsion that the Royal Fleet Auxiliary Service was formed.

The RFA was a product of the days of coal-burning ships. It was officially constituted by Royal Charter in 1911. At first it was mainly a coal bunkering and stores carrying service, but as oil-burning warships replaced coal-burning vessels before and during World War I, it was adapted to cater for this new need by the building of a tanker fleet. From that time it grew rapidly and in World War II its ships served in every naval theatre of operations from the Arctic to the Pacific.

The ships of the RFA Service, although working in close liaison with the Royal Navy, have always been manned by officers and Ratings of the Merchant Navy who sail under the Blue Ensign.

From eight ships at the outbreak of World War I, the Service today is comprised of about 4,000 Officers and men and some 42 specially equipped ships, including fast replenishment ships, large 2nd line tankers, stores support ships, fast cargo vessels and a helicopter support ship designed specially for the training of RN helicopter crews.

RETIREMENT

W. R. JAMES, R.N.S.S.

Mr. W. R. James, Chief Draughtsman, A.U.W.E., retired on 17th June, 1968, after 44 years continuous service with the Admiralty.

Entering Pembroke Dockyard as an Engine Fitter Apprentice in 1924, he transferred to Portsmouth when Pembroke Yard closed in 1926. His drawing office career began in 1934 when he entered the Torpedo Tube Design Office at Portsmouth; he has been engaged on weapon discharge problems ever since, serving at Portsmouth, West Howe and Portland.

The Director, presenting Mr. James with a silver condiment set made reference to his long service and the valuable and responsible work that he had done, also to his varied leisure interests. Mr. James, in reply paid tribute to the assistance he had received from his colleagues and mentioned the pride he had felt in being a member of the U.L.E. at West Howe prior to joining A.U.W.E. at Portland.

His many friends and colleagues wish Reuben James a long and happy retirement. Most of them have the conviction that the majority of his hours of retirement will be spent in his well loved garden.

OBITUARY

A. C. TREVETT, B.Sc., M.I.E.E., R.N.S.S.

Mr. Trevett died on 30th April, 1968 after a long illness. Having completed 24 years, he had retired from the Admiralty service in October 1967, when he was serving at A.U.W.E.

He was educated at the Brighton Municipal Technical College, where he obtained an external B.Sc.,(London) degree with second class honours in Electrical Engineering.

After serving a four year graduate apprenticeship with Metropolitan Vickers at Manchester, Mr. Trevett joined COSMOS Valve Manufacturing Company at Edmonton as a Development Engineer, where he was concerned with the layout of special machine tools for making thermionic valves and the day to day running of the factory.

In 1943 he joined the Admiralty service at the Mine Design Department at Leigh Park, Havant as a Temporary Technical Officer. In 1946 Mr. Trevett was assimilated into the R.N.S.S. as a Senior Scientific Officer and was promoted to P.S.O. in 1947. During the whole of his service he was closely concerned with R. and D. work on mines and mine counter-measures problems.

His hobbies included doing up old cars at which he was quite adept.

He leaves a widow and two sons to whom we offer our deepest sympathy at their sad loss.

F. E. MITTINS, R.N.S.S.

His many friends and colleagues in A.S.W.E. and in the R.N.S.S. were deeply shocked by the sudden death of Frank (Ginger) Mittins on the 4th June, 1968 at the early age of 50.

As a young man he had been apprenticed to the Great Western Railway, Swindon, as a Pattern Maker. He had subsequently acquired a very thorough and widespread knowledge of foundry work, and it is in this field that he made his mark with the R.N.S.S.

He joined the Mine Design Department, H.M.S. *Vernon* in 1939. When *Vernon* was bombed, he earned a commendation for rescue work as an Air Raid Warden. Later he was transferred to U.C.W.E. West Leigh, finally joining A.S.R.E./A.S.W.E. during the 'Way Ahead' in 1959. At the time of his death he was in charge of A.S.W.E's pattern making and foundry departments and of the workshops of the Establishments extensions.

He was a gifted craftsman with much artistic talent, and a generous man who devoted a lot of his time to helping the less fortunate around him. In particular he will be missed by the Spastic children in Portsmouth for whom he devised and made many ingenious aids to lessen their handicaps.

He leaves a widow, who was also formerly at U.C.W.E., and a son.

CORRESPONDENCE

To: The Editor

Journal of the Royal Naval Scientific Service.

Dear Sir,

I have read Mr. F. E. Birbeck's article in the May *Journal* on a Gallium Arsenide Array for communications with great interest and some trepidation. I venture to offer the following comments:

(a) Mr. Birbeck states that it is not easily subjected to tapping. But what is to prevent " the enemy " from having a suitable silicon P-I-N photo-diode to detect our signals ?

(b) The system is to cover only 3° in elevation. This means that the capsule must be stabilized, otherwise signals will be lost in very small angles of roll. This means a considerable increase in bulk weight and cost.

(c) I see that re-assembly of the Capsule must be carried out in clean, dry air. This is a commodity that H.M. Ships did not have in my day. Do they have it now ?

It would be interesting to know if the laser beam can be used as a carrier for Voice, or whether one would be limited to Morse.

Yours faithfully,

J. H. Gretton, Commander R.N.(Retd.)

Department of Naval Physical Research

To: The Editor

Journal of the Royal Naval Scientific Service.

Dear Sir,

I have read Cdr. Gretton's letter with interest and I should like to make the following observations in reply.

In the first place the system would not be subject to tapping in the same way as radio, because the laser transmitter, like the normal signalling lamp has a clearly defined transmission solid angle which is limited to visible range.

The second question on stability has been covered in separate studies. These show that a simple damped gimbal system could accommodate the transmitter and its associated receiver, not described in the paper. The whole unit would be about 18 inches in diameter and 24 inches high.

A supply of clean dry air for reassembly after repair would be readily available by tapping the source which supplies the cooler in the transmitter. However one would almost certainly conform with modern practice and change the complete laser unit in the same way as one would change a conventional light source.

It is certainly possible to use the laser system for telephony as well as telegraphy. In this case one would reduce the pulse length to accommodate the higher pulse repetition frequency required, without any excessive increase in the mean power. A study of this mode of operation shows that the nett effect would be to reduce the maximum range by about 50%.

Yours faithfully,

F. E. Birbeck

Services Electronics Research Laboratory

To: The Editor

Journal of the Royal Naval Scientific Service.

Dear Sir,

In Mr. Brian Spencer's interesting review of the development of the submarine (*J.R.N.S.S.*, **23**, 3 (May 1968)) he implies that " difficulties with the Walter turbine " resulted in no further applications after the German Type XVII. I am surprised that he does not refer to H.M.S./Ms *Explorer* and *Excalibur*, which successfully exploited this design of propulsion plant, and which briefly in the 1950s held the underwater speed record (for endurances of hours rather than minutes or days). It is a matter of history that the R.N. decided to equip itself with Rolls Royces rather than Minis in the submarine field, but designers of nuclear submarine steam machinery should spare more than a passing thought for these boats, where 14,000 S.H.P. steam turbine machinery, including " reactor ", was installed in a 15ft. 6in. diameter hull with a machinery compartment length of 42ft. 6in.

Mr. Spencer implies that the schnorkel was a German development, whereas of course the credit should go to the Royal Netherlands Navy. The Dutch have always been pioneers in underwater warfare, since the seventeenth century, when Ben Jonson reported in " The Staple of News ":

" They say here, that one Corneliusson
Hath made the Hollanders an invisible eel
To swim the haven at Dunkirk, and sink
The shipping there . . .
'Tis an automata, runs under water,
With a snug nose, and hath a nimble tail
Made like an augur, with which tail she wriggles
Between the costs of a ship, and sinks it straight ".

Yours faithfully.

E. J. Macnair

Ship Department

Notes and News

Admiralty Materials Laboratory

Mr. D. A. Fanner transferred to D.M.R.(N) on promotion to S.P.S.O. on 2nd September, whilst Mr. D. W. Butcher, S.S.O., left with permission on 29th July, 1968, to take up a lectureship in Australia.

Mr. R. Hillman, E.O., transferred to A.U.W.E. on 16th September and Miss B. E. J. Spreadborough, E.O., left with permission on 17th September, 1968, to take up teaching.

Miss J. M. Baker, E.O., retired on 31st July, 1968, after 23½ years' service. She joined T.E.E. in 1945 and moved to N.C.R.E. in 1949. Owing to a desire for a change from laboratory work she was given a short course of library training in 1952 and was then transferred to A.M.L. where she took charge of the library organisation. Miss Baker was presented with a cheque by Dr. T. C. J. Ovenston on behalf of her colleagues, with their best wishes for a happy retirement. Miss E. Briggs, A.E.O., has joined A.M.L. from N.S.T.I.C. from 15th July, 1968, to take charge of the library following Miss Baker's retirement.

Dr. C. A. Parker is the author of a text book entitled "Photoluminescence of Solutions" which was published by Elsevier Publishing Co. in July, 1968.

Dr. D. J. Godfrey attended a spring course organised by the Metals and Metallurgy Trust of the Institute of Metals and Institution of Metallurgists, where he presented a paper on "The Use of Ceramics in High Temperature Engineering".

Dr. R. H. Warren visited the U.S. in July, 1968, in connection with his work as Secretary of D.M.R.(N)'s Materials Defect Evaluation Working Party. He visited several U.S. naval and industrial organisations and discussed the evaluation of defects in materials and structures.

Mr. J. A. Wyatt visited Den Helder at the invitation of the Royal Netherlands Navy in June, 1968, to attend a symposium on boiler problems, where he read a paper on "Chemical Cleaning of Boilers — R.N. Experience".

A paper entitled "Phosphorescence of Benzophenone in Fluid Solution" by C. A. Parker and Thelma A. Joyce was published in *Chemical Communications*, 1968, p. 749.

⚓ ⚓ ⚓

Admiralty Surface Weapons Establishment

At a discussion at the Institution of Electrical Engineers at Savoy Place on the 16th May on "Frequency Scanning Antennas", papers were read by:

Dr. J. Croney (A.S.W.E.)

Mr. M. F. Radford (Marconi Company), and

Mr. G. A. Hockham (Standard Telephone Laboratory).

The work described by the Marconi Company was supported by A.S.W.E. The discussion was reported in IEE News of 17th June.

At the 14th Annual Tri-Service Radar Symposium (Fort Monmouth, U.S.A.) two papers were presented by A.S.W.E.:

"Land and Precipitation Clutter Measurements at C-Band", by Mr. A. Reiss, Dr. W. Whitlock and Mr. M. Smith, and

"Some Effects of Radar Polarization in Sea Clutter Suppression Techniques", by Dr. J. Croney and Mr. A. Woroncow.

At the Symposium on "Electromagnetic Windows" held at Georgia Institute of Technology, Atlanta, U.S.A., a new type of radome was described by Mr. W. D. Delany (A.S.W.E.) in a paper entitled "A Strut Reinforced Single Skin Spherical Radome".

At the 10th IEEE Symposium on "Electromagnetic Compatibility" held at Seattle, U.S.A. in July 1968, an international session was included for the first time. Mr. H. Salt (A.S.W.E.) presented a paper entitled "The Surface Transfer Impedance of Coaxial Cables", and this was subsequently judged to be the most outstanding paper in the International Session, and received a symposium award.

The Admiralty Board has approved the award of £500 each to Messrs. D. H. O. Hider and T. A. Tugwood in respect of their work on segmented and differential slip-ring units. Mr. Hider is now serving as Scientific Adviser (Underwater) to the British Navy Staff, Washington and Mr. Tugwood is currently serving at A.S.W.E.

Mr. L. F. Jones, one of the establishment's Senior Draughtsmen, has been granted permission to complete his application for a patent in respect of an ingenious new rotary diesel engine which he has conceived. A small model has been constructed and adequately demonstrates the principle.

Recent visitors to the establishment have included the Controller of the Navy and the Director General Weapons (Naval).

⚓ ⚓ ⚓

Naval Construction Research Establishment

It is with pride, tinged with regret, that we record the resignation of Dr. James Lawrence King from the post of Chief Scientist at the Naval Construction Research Establishment. Dr. King has left to take up the appointment of Regius Professor of Mechanical Engineering at Edinburgh University.

Dr. King graduated B.A. (with distinction in Part 3) at Jesus College, Cambridge, in 1942. In 1948 - 51 and 1952 - 53 he attended Imperial College, London, as a part-time student in Applied Mathematics. At the end of this higher course of study he attained the degree of Ph.D.; his thesis was entitled "Motion of an Elastic String".

Dr. King first joined the Admiralty during the war as a Temporary Experimental Officer in August, 1942 and, after the cessation of hostilities he quickly rose through the ranks of Scientific Officer, Senior Scientific Officer and Principal Scientific Officer to become a Special Merit Senior Principal Scientific Officer in July, 1955. In January, 1961, he was promoted to the rank of Deputy Chief Scientific Officer when he became the Chief Scientist at N.C.R.E.

During Dr. King's term as Chief Scientist the Establishment has flourished and has undoubtedly obtained a reputation for integrity of scientific thought and achievement. Dr. King's benign personality and his ability to reach the hub of any problem presented to him and suggest a logical method of attack and solution, will be missed. We wish him every success

in his new appointment where, doubtless, the same qualities he exhibited in the Naval service, will result in an outflow of well-tutored acceptable students, possibly inculcated with a desire to join the Royal Naval Scientific Service.

⚓ ⚓ ⚓

H.M.S. *Exmouth*

H.M.S. *Exmouth*, the first major warship in the West to be propelled entirely by gas turbine engines, commissioned at Chatham Dockyard at 11.30 a.m. on Saturday 20th July.

The service was conducted by the Chaplain of the Fleet, the Ven. Archdeacon C. Prior, the Roman Catholic Chaplain, Medway Sub-Command, the Rev. J. Dooley, and the Officiating Minister of the Church of Scotland and Free Churches, the Rev. D. C. Lapworth.

The ceremony was attended by Vice Admiral W. J. Parker, Flag Officer Medway, and afterwards the families of the Ship's Company were entertained to lunch on board the ship.

A frigate of the "Blackwood" class, H.M.S. *Exmouth* was built by J. Samuel White and Co. Ltd. at Cowes and completed in 1957. After service with the 3rd Submarine Squadron as a target ship, and then the Fishery Protection Squadron, she started a major conversion programme at Chatham in 1966 to an all gas-turbine powered ship. The aim was to produce a working test bed for the next generation of warships and to produce a gas turbine ship which could be compared with similar ships with conventional power plants. She is now fitted with two Rolls Royce Proteus engines for cruising and a Rolls Royce Olympus engine for full power.

H.M.S. *Exmouth* is at present conducting trials from Chatham, and will in due course continue the trials in different parts of the world under varying climatic conditions.

Books available for Review

Offers to review should be addressed to the Editor

Automation in Anatomy and Physiology. J. Rose. Oliver & Boyd Limited. 1967. 7s. 9d. (No. 1585).

Basic Astronomy. P. Moore. Oliver & Boyd Limited. 1967. 7s. 6d. (No. 1588).

Contact and Frictional Electrification. W. R. Harper. Oxford University Press. 1967. 70s. (No. 1600).

Basic Electricity. Various Authors. W. Foulsham & Co. Ltd. 1967. 30s. (No. 1608).

Jane's Surface Skimmer Systems 1967/68. Edited by R. McLeavy. Sampson Low, Marston & Co. Ltd. 1967/68. (No. 1620).

Measuring Hi-Fi Amplifiers. M. Horowitz. W. Foulsham & Co. Ltd. (Tech. Books). 1967. 25s. (No. 1621).

Probability and Hypothesis Testing. L. N. H. Bunt and A. Barton. G. Harrap & Co. Ltd. 1968. 27s. 6d. (No. 1627).

Know Your Sweep Generators. R. G. Middleton. Foulsham-Sams Ltd. 1968. 26s. (No. 1633).

A Course in Pure Mathematics. M. M. Gow. English University Press Ltd. 1968. 30s. (No. 1634).

Enzymes. D. W. Moss. Oliver & Boyd Ltd. 1968. 7s. 6d. (No. 1639).

The World of a Gynaecologist. C. Scott Russell. Oliver & Boyd Ltd. 1968. 7s. 6d. (No. 1644).

Exploration of the Moon by Spacecraft. Z. Kopal. Oliver & Boyd Ltd. 1968. 7s. 6d. (No. 1645).

Bridges and other Null Devices. R. P. Turner. W. Foulsham & Co. Ltd. 1968. 26s. (No. 1648).

Worked Examples in Higher National Certificate Mathematics. 2nd Edition. R. H. Clark. George G. Harrap & Co. Ltd. 1968. 28s. 6d. (No. 1661).

Cambridge Tracts in Mathematics and Mathematical Physics 57 Metric Spaces. E. T. Copson. Cambridge University Press. 1968. 30s. (No. 1663).

Linear Differential Operation. M. A. Naimark. George G. Harrap & Co. Ltd. 1968. 40s. (No. 1667).

General Engineering Science. R. J. Besanko and T. H. Jenkins. Oxford University Press. 1968. 16s. (No. 1670).

Cableships and Submarine Cables. K. R. Haigh. Adlard Coles Ltd. 1968. 105s. (No. 1671).

Essentials of Sound. F. J. H. Dibdin. Macmillan & Co. Ltd. 1968. 18s. (No. 1672).

Physics. Marshall, Pounder and Stewart. Macmillan & Co. Ltd. 1968. 60s. (No. 1673).

Interfacial Cohesion. Inter-Service Metallurgical Research Council. A. P. Greenough. H.M.S.O. 1968. (No. 1674).

Chareo Harhour. G. Blaindon. Weidenfeld & Nicolson Ltd. 1968. 42s. (No. 1675).

Optical Oceanography. N. G. Jerlov. Elsevier Publishing Co. 1968. 100s. (No. 1676).

Diffusion Kinetics for Atoms in Crystals. J. R. Manning. D. van Nostrand Co. Ltd. 1968. 91s. (No. 1677).

Elements of Marine Ecology. R. V. Tait. Butterworth & Co. 1968. 62s. (No. 1678).

Astronomical Objects for Southern Telescopes. E. J. Hartung. Cambridge University Press. 1968. 50s. (No. 1679).

Thermodynamics (2nd Edition). W. C. Reynolds. McGraw Hill Publishing Co. Ltd. 1968. 107s. 6d. (No. 1680).

Engineering Outline 2. A. A. H. Scott, Macmillan & Co. Ltd. 1968. 60s. (No. 1681).

Magnetic Compasses and Magnetometers. Alfred Hine. Adam Hilger Ltd. 1968. 210s. (No. 1682).

Detection, Estimation and Modulation Theory Part I. H. L. van Trees. John Wiley & Son Ltd. 1968. 175s. (No. 1683).

Bessel Functions with some Physical Applications. C. J. Tranter. English University Press. 1968. 50s. (No. 1684).

Examples and Exercises in 'A' Level Physics. H. V. Pilling. English University Press. 1968. 8s. (No. 1685).

Observations in Modern Astronomy. D. S. Evans. English University Press. 1968. 84s. (No. 1686).

Large Scale Provisioning Systems. Edited by J. Ferrier. English University Press. 1968. 126s. (No. 1687).

Photoluminescence of Solutions. C. A. Parker. Elsevier Publishing Co. 1968. 230s. (No. 1688).

Book Reviews

Powder Metallurgy, Practice and Applications. By R. I. Sands and S. R. Shakespeare. Pp. x+261. London. George Newnes Ltd. 1966. Price 70s.

One of a new series by Newnes entitled " International Monographs on Materials Science and Technology ", for which the advisory editor is a certain N. L. Parr, this textbook is described as reviewing the practice and applications of powder metallurgy (which it does very well indeed) and the principles upon which the technology is based (not quite so well). The headings of the 12 chapters—Introduction: Metal Powders, their Properties and Production: Shaping of Metal Powders: Sintering: Engineering Components: Tool Materials: Bearing Materials: Permeable Metals: Sintered Friction Materials: Electrical and Magnetic Materials: Refractory Metals: and Miscellaneous Applications of Powder Metallurgy —accurately represent the contents, and what a wide field of technology is covered! Your reviewer is now aware that, in the diamond tools used for rock drilling, diamonds bonded in an iron matrix (itself an indication of the extent of powder metallurgy) have been found suitable for Portland stone, while granite needs a softer matrix.

The approach of the book and the style of writing are clear and authoritative. For example, when carbonyl iron powder is first mentioned there is a brief explanation of the carbonyl process itself, and there is a reference to this in the index (but there is not a reference to the related formate process). The language used is English, of a quality which it is a pleasure to acknowledge, but did something happen in the last quarter of the book? Here the manner of presentation, and the general writing, are detectably below the high standard set in the rest of the book.

One trivial misprint was found in 250 pages. There are about 70 line diagrams and 20 photographs, many of the latter obviously taken from sales literature. Some of the diagrams represent typical graphs of property X against variable Y, and as such these are given without units. This is all right in the seminar room, but rather disconcerting in a book of this calibre.

Principles and theory are less well handled. The " well-known Darcy equation " is badly presented (and not indexed), while viscosity and the Reynolds number each appear in two different places with different notation and terminology. It is implied that a permanent magnet represents a store of energy which can be withdrawn at will. The high specific gravity of tungsten is the only reason given for its use as a γ-radiation shield.

These peripheral criticisms made, the authors are to be congratulated on the breadth and the quality of their book. As a review of the " state of the art " it is confidently recommended, in spite of the price.

A. P. Bennett

Nelson's Navy. By P. Richardson. Pp. vi + 106, London; Longmans, Green & Company Ltd., 1967. Price 5s.

This excellent little book is lavishly illustrated, mostly from contemporary paintings and engravings from the originalss in the National Maritime Museum. It also has an excellent exploded drawing of the *Victory* and some useful sketch charts. It starts with the ships and then works through the officers, petty officers and men, their work on board ship, punishments, life on board ship, the Spithead and Nore mutinies, blockade, pursuit of *Villeneuve,* preparations for battle and action stations. It finishes with a very useful glossary. As it is written with schoolchildren particularly in view there is a slightly provocative page of things to do. Provocative, that is, to the reviewer in that although the bulk of the material is evidently derived from the National Maritime Museum a visit to the Museum is not included. It can be recommended to anyone interested in the Navy of Nelson's time.

D. W. Waters

Computer Basics. By Technical Education and Management Inc. Vol. II **Analog Computers—Mathematics and Circuitry.** Pp. 224. Vol. III **Digital Computers—Mathematics and Circuitry.** Pp. 224. Vol. V **Analog and Digital Computers—Organisation, Programming and Maintenance.** Pp. 224. Slough; W. Foulsham & Co. Ltd., 1966. Price 30s. each volume.

These three volumes are part of a five volume series prepared by an American firm called Technical Education and Management Inc. They spring from a course produced about 1960 by the same firm for the U.S. Navy which was designed to train U.S. Naval electronics technicians in computer technology. This reviewer is profoundly grateful that he only undertook to review three out of the five volumes, for this was tedious enough. However in case anyone is interested the missing two are:—

Vol. I—Introduction to Analog Computers

Vol. IV—Digital Computers—Storage and Logical Circuitry.

It is stated that these volumes are written to be easily understood by a reader with no prior knowledge of computer systems but with some background of basic electronics and a working knowledge of algebra and trigonometry. However the working knowledge required is minimal indeed, and because of this the text is frequently extremely laboured. For example the reader is not assumed to have any skill in algebraic manipulation and every step in the development of an equation is set down in minute detail e.g. when dealing with the input impedance of an operational amplifier we have:

$$i = \frac{e_g(1 + A)}{Zf}$$

$$\frac{e_g}{i} = \frac{e_g}{\frac{e_g(1 + A)}{Z_f}}$$

$$= \frac{Z_f}{1 + A}$$

I cannot believe that anyone capable of maintaining and operating digital or analog computers is incapable of following the text without every intermediate step being detailed. Elsewhere in the text (Volume III) in a discussion on interpolation formulae, Aitken's formula is quoted without explanation and in a form which will be meaningless to the reader with the mathematical experience assumed by the compilers elsewhere in the text.

Volume II (Analog Computers—Mathematics and Circuitry), describes the operational amplifier and discusses some of its problems. It includes a fairly comprehensive description of methods used to compensate for drift in the d.c. amplifier and describes how to set up a simple second order differential equation on the analog computer. This is reasonably well done but due to a numerical slip in the example used to describe amplitude scale factoring the reader is likely to be somewhat confused. There is a description of the methods used to generate mathematical functions and an outline of the components used in analog computers. Then, quite unaccountably, there is a digression on servo-mechanisms in the chapter entitled frequency multiplication. This is out of place and appears to serve no purpose in this part of the book. The next chapter entitled Auxiliary Analog Devices begins with a description of semi-conductors followed by saturable reactors—neither in sufficient detail or with sufficient clarity to justify their inclusion. There is then a more useful description of the various transducers, recording techniques and transmissions systems used in analog computation. In general while there is a lot of useful information, albeit described in a superficial way, there is much in the volume which appears to be mere padding and it could benefit from critical pruning and editing.

Volume III (Digital Computers—Mathematics and Circuitry) contains useful information on some iteration, perturbation and relaxation methods used in preparing computer programmes. However it suffers from the same faults as Volume II and contains much unnecessary material e.g. a detailed description of the neon tube sawtooth generator. In addition the circuitry described uses electronic valves as the active element; semi-conductor diodes are mentioned but I cannot recollect any circuit using transistors. The section on Boolean algebra is extremely sketchy. For example there is no mention of Venn diagrams or De Morgan's theorem.

Volume V (Analog and Digital Computers—Organisation, Programming and Maintenance), contains some good material e.g. description of binary multipliers and forward backward counters in hybrid computation and some very trite material e.g., in a section on maintenance "If a cup of coffee were to fall into the mechanism of a digital computer it would undoubtedly wreak havoc. You can probably visualise the effect that would be produced by the melting of a candy bar that has been left casually on a deck of data cards; 'chocolate' is a fighting word to those repairmen who have witnessed its damaging effects". It is again very uneven and where it describes circuitry this is valve and not transistor. There is a good section on analog to digital converters including a very thorough discussion on methods of overcoming the ambiguity involved in using the natural binary codes.

Summing up I cannot recommend these books to the type of reader I believe them to be intended for i.e., a junior technician. There are a number of printing errors which will mislead; there is a great deal of redundant information (I wonder if there is any significance in the fact that they all have 224 pages) and they are in some instances quite out of date. Additionally some of the diagrams appear to have been reduced in scale and are difficult to understand.

L. S. Bryson

Olefins and Acetylenes. By F. D. Gunstone. Pp. 68. London; The English Universities Press Ltd. 1966. Price 8s. 6d.

This book is in the form of a "Programmed Text" and is the third of a series of Chemical Science Texts, intended for sixth formers and junior students at Universities and Technical Colleges. The text is arranged in short blocks, consisting of a statement on structure, preparation or property, followed by a question based on this statement and then the answer to the question. In places statement and question are combined in one block. It must, therefore, be read in the order given and, preferably, a complete chapter at a time. Presumably, it is a form of "teaching machine", where the student can proceed at his or her own speed and re-read whatever section has been forgotten or not understood. It could hardly be used as a reference book, although it is packed with factual information regarding olefins (and dienes), and acetylenes. As the text proceeds, more and more complicate reactions are described, with the result that the rate of reading slows down. The reviewer found it quite impossible to read a whole section in one session; maybe a younger mind could withstand this type of "cramming" more easily.

As more and more textbooks and scientific literature are produced, perhaps there is a need to cut down on the sheer bulk involved. Since there also appears to be a shortage of teachers the use of various machines or aids would also appear necessary. This book achieves both objects and should be welcomed, but one misses the little gems which appeared in the "old-fashioned" textbooks as one ploughs through a programme of facts.

A. J. Bloom

Vibration in Civil Engineering. Ed. B. O. Skipp. Pp. 302. London: Butterworth & Co. Ltd., 1966. Price 85s.

Anyone working in the field of vibration and shock is almost certain to be the recipient from time to time of plaintive requests of which the following is a typical example: "We have put up a new building for our test instrumentation and are experiencing trouble from vibration which we think comes from our machine shop next door. Can you tell us what to do about it?" More likely, though, the request will be not for advice, but for assurance that certain belated action already decided upon, perhaps by now in hand, is going to be successful, bearing in mind that the proposed panacea will be (a) quicker, (b) cheaper, (c) less trouble, than more sure and fundamental remedies. The polite reply can now be given: "I can help you most by recommending you to consult 'Vibration in Civil Engineering' in which you will find a number of highly practical papers, together with further references and actual case histories. Come back again if you wish to change your mind. And by the way, make sure it is the machine shop which is the cause."

The 1965 Symposium, of which this book is the outcome, is claimed to have been the first of its kind to be held in the United Kingdom. It was organized by the British National Section of the International Association for Earthquake Engineering—a rather ambiguous title which one hopes does not mean what it says. There are 26 papers whose authors are drawn from an international field; the earthquake aspect does not by any means dominate the papers.

The book commences with a useful general paper by R. J. Steffens of the Building Research Station, which summarizes the elementary theory and practice of vibration isolation, and at the same time manages to bring in sufficient detail about selected cases as to sustain interest in the reality of the subject. Extensive references are given. Two papers on the effects of vibrations on buildings, and on vibrations in resiliently-mounted machines, are then followed by sections labelled as the transmission of vibration, instrumentation, the dynamic behaviour of soils, the dynamic behaviour of founda-

tions, current practice in structural design, and current practice in structural isolation. Whilst it would be impossible to comment upon all the individual papers here, the following might be mentioned to indicate their scope. Professor N. M. Newmark, University of Illinois, deals with shock response spectra and shock resisting mountings for ground-based structures in a realistic (one dare not say 'down-to-earth') manner which the academic title 'Notes on Shock Isolation Concepts' does not suggest. P. Grootenhuis of Imperial College (well-known to members of the Society of Environmental Engineers for his own work on vibration) and A. O. Awojobi deal with the measurement of the dynamic properties of soil using an electro-magnetic vibrator at constant amplitude to measure resonance frequencies, and show good agreement between experimental results and values expected from fundamental quantities in a particular case. G. L. Grant describes a method of measuring receptance (the complex ratio of displacement to exciting force) using an electro-dynamic exciter to drive the bearing support of a large turbine. This method has now however been superseded by the use of more direct instrumentation which will automatically plot mechanical impedance over a frequency range on an XY plotter. J. H. A. Crockett gives over 30 examples of potted case-histories of shock and vibration problems; this paper is one of the most fascinating in the book, and is invaluable for conveying in palatable form the general philosophy of vibration isolation. The remaining papers all embody information of great use and relevance.

Some subjects will necessitate more specialized reading; instrumentation, for example, the description of which has been highly generalized, and mechanical impedance, which is hardly mentioned as such. The presentation of the book is good, and the printing is clear and on matt paper, so that one can read it in artificial light without having to dodge reflections. There are a few trivial printing errors, for example, 'Psuedo-velocity' in the index is followed by 'Pulbic Health Acts'. All in all, this book can be firmly recommended to the mechanical or structural engineer, indeed to anyone who is either on the receiving or the transmitting end of advice on shock and vibration problems. One consultation of the book, especially at the drawing office stage of a building projeet, eould easily save its cost a hundredfold.

L. S. LePage

Modern Communication Principles. By S. Stein and J. J. Jones. Pp. ix + 382. New York; McGraw-Hill Inc. 1967. Price $15.

This book, produced as an extension of a review of principles of modern communications prepared by the authors in 1964, is intended as a self-contained work for practising engineers who require an introduction to the advanced theoretical models in radio communieation theory.

The approach is from the "systems engineering" viewpoint of communication theory and the later ehapters highlight material which has, until reeently, been unavailable in book form.

The first eight chapters of the book provide background and a review of material with emphasis on modern techniques.

The next five chapters introduce digital signalling, mainly in terms of binary systems, and include treatments of matched filtering and correlation detection. Two chapters are then devoted to M-ary and coded transmissions.

In the final two chapters, the results for binary systems are extended to real communieation channels with fading signals, including the use of diversity combining techniques for dealing with such fading.

The background material contained in the first eight chapters constitutes an excellent introduction to techniques applied to eommunication theory such as frequency spectra and Fourier theory which together with correlation methods, random processes and noise analysis provide a useful introduction to amplitude, angle and pulse modulation principles and multiplexing techniques covered in the next four ehapters.

The treatment of modulation techniques is complete and comprehensive from a "systems" point of view, particular attention being given to wide and narrow band frequency modulation and relative signal to noise ratios and their improvement. The chapter on pulse modulation provides an adequate coverage of sampling principles and pulse code modulation (delta modulation, being merely mentioned). Noise analysis in P.C.M. systems is covered in some detail and thus the section comprehensively covers modern modulation techniques with particular reference to noise considerations.

Principles of multiplexing are next briefly covered before the introduction to digital signalling and principles of eoherent and non-coherent detection are considered. The remainder of the book is concerned with binary on-off, frequency shift and phase-shift keying which are briefly outlined followed by extensive coverage of matched-filter and correlation detection and rounded off by eonsiderations of ehannel eapacity and error-eontrol-eoding. The final chapter on diversity techniques is followed by a list of some 28 references relevant to extension of the material covered by the book.

Summarizing, the book is probably the most comprehensive review of modern principles in eommunication theory published to date. The price of $15 does however seem to be somewhat excessive and perhaps prohibitive for a private library but the material matter should ensure the book of a place in any complete technical library.

D. Robson

Ethyl Aeetoacetate and Related β-Keta Esters. By F. D. Gunstone. Pp. 43. London: The English Universities Press Ltd. 1966. Price 6s. 6d.

This book is the second of the series of Chemical Science Texts and follows the same pattern as "Olefins and Acetylenes".

The chemistry of these compounds is quite complicated and hence this book makes very heavy reading. It is difficult to see why this particular subject was chosen for the second book of the series. The chapters cover the preparation of ethyl acetoacetate and the Claisen condensation, tantomersion, the hydrolysis, ketonic and elonic properties of β-keto esters, and reactions of the activated methylene group. The final Summary is solely questions and answers on the preceding chapters.

The same general remarks given on "Olefins and Acetylenes" apply here also, and it must be emphasized that, for people reading this series of books volume by volume, Volume 2 is not designed to endear one to this system of learning.

A. J. Bloom

Linear Automatic Control Systems with Varying Parameters. By A. V. Solodov. Pp. xii+270. London; Blackie & Son Ltd. 1966. Price 75s.

There comes a time in any young control engineer's life when he is confronted with the awful truth that the nice block diagrams with their simple Laplace transforms which he could manipulate with ease bear little relationship to actual practice. Equally, the realization that, even in linear systems, components might change their parameters with time could cause him to throw away his Nichols charts in disgust and revert to (relatively) simple electronics. He should, perhaps, read this book first.

A general introduction is first given, including several fairly simple systems in which it is shown that time-varying components are more prevalent than one would first imagine. Six chapters follow, set out approximately in order of increasing mathematical difficulty. The first chapter discusses in detail the impulse response function of a linear system and the second chapter deals with block diagram transformation of such systems. The third chapter gives approximate methods of deriving impulse response functions, while the fourth and fifth chapters discuss problems arising and possible solutions when signals of given and of random time functions are applied to the linear system. Finally, the sixth chapter investigates systems with variable parameters and random inputs by means of simulation techniques.

By any standards, this book is a *tour de force*. Several new (to your reviewer) techniques are demonstrated, notably the methods of block diagram transformation, and invariably the necessary steps taken to reach conclusions are clearly set out. This is not, however, a book for the beginner. The standard of mathematics is high, although the basic concepts are explained generally in simple terms. One cannot tell how freely the original work has been translated, but the result is a flowing text which is a pleasure to read. It is also refreshing to see that nearly half the cited references are by "foreign" (*i.e.* non-Russian) authors. So often does one see a long list of Russian works and only one or two "Western" items given as references in Russian textbooks.

A relatively minor criticism is that the numerous diagrams in the book could have been made a little larger and isolated more from the text. One would suspect that the original Russian blocks were used, suitably altered in terms of symbols. Even bearing this in mind, your reviewer has no hesitation in recommending the book for both technical library and designer's bookshelves.

J. E. Etheridge

Theory of Games. Editor: A. Mensch, Pp. 490. London; The English Universities Press Ltd. 1966. 75s.

Game theory came to life with the publication of a book by V. Neumann and Morgenstern. The book was devoted to the application of game theory to economics but the publication of the book soon led to military theorists recognizing the possible use of the theory as an analytical approach to military problems and distinct from gaming. Ever since, controversy has raged about its usefulness in this sphere and even acrimony has resulted between the proponents and opponents of the use of the technique. One of the interesting outcomes of this controversy is the opportunity Morgenstern has taken in the book to castigate denigrators such as Zuckerman.

The book is often lively and also often controversial but is a valuable guide to the field of game theory as applied to warfare. The shortcomings of game theory are well known—it has been sometimes called the pessimist's approach to making a choice—but there are still valid fields of application both to military and civil problems. The field of weapon assessment is generally agreed to be such a valid field but most of the difficulty of such an application resides in obtaining the pay-off matrix.

To those who want a succinct introduction to game theory the article in the book by Vajda contains an elegant summary of the two-person zero-sum game with an explanation of saddle point, dominant strategies, and pure and mixed strategies, the key words in this type of game.

Game theory is an analytical approach to the study of human conflict: the game in general may be many person and not necessarily zero sum. The latter implies that the interests of the opponents are not directly opposed as it would be in a zero sum game and this condition may often exist in military operations. Non-zero-sum games were studied in detail in the original book by V. Neumann and Morgenstern as the latter points out in the book under review but are in general difficult. The problem of the prisoner dilemma is a classical example and was first solved by Howard. An interesting study of this problem as a paradox has been given in *Scientific American*: the present book quotes an interesting example from Rousseau's book on Inequality and another from Xenophon. Both these examples illuminate and enliven the book.

The book is a collection of lectures delivered at a NATO sponsored conference at Toulon in 1964. As befits a bilingual organization the articles are in French and English, the ratio of the two being nearly unity. The book is divided into three parts; Part I is mathematical models, Part II military applications, and Part III discussion and synthesis.

The mathematical models sections tend to be abstract in nature. It is of course true that game theory is a mathematical discipline and it is claimed that it in turn has led to advances in other branches of mathematics. One of the interesting lectures in Part I is the theory of MAX-MIN and its applications. In this game the minimizing player acts after the maximizing player and further with full knowledge of the latter's choice; such a game has military application to the attack in established concrete installations. The very common military problem of pursuit and evasion is treated in a paper by Prof. Grenader of Stockholm.

Part II deals with a large number of military problems about equally divided between the services, and is a valuable collection of specialized topics and a good indication of what types of problems are amenable to solution by game theory.

The discussion in Part III is lively and entertaining as well as throwing some light on the general problems of game theory and where it is likely to go in the future. The two articles by Morgenstern and Schelling are of particular interest in this context.

The book is strongly recommended to students interested in game theory and particularly in its applications to military problems.

R. A. M. Bound

Naval Review, 1967. United States Naval Institute. Pp. 335. Annapolis; U.S. Naval Institute, 1967. Price $12.50.

The United States Naval Institute's "Naval Review, 1967" follows on much the same lines as the original (1962 - 63) issue, which was reviewed in the July 1963 number of this Journal. It consists of a preface by the Editor and 12 essays on various matters of naval interest, the majority written by distinguished American experts in their various subjects, for the most part U.S. Naval Officers. There follow four appendices. The only non-American contributor (though one of the appendices is anonymous) is Vice Admiral B. B. Schofield, who was incidentally one of the two European contributors to the original issue.

The essays include a description of Operation Starlite, the first substantial American success in the Vietnamese War (which would be more readable if it were not bedevilled in almost every paragraph by a deluge of apparently meaningless and unrelated figures, initials and abbreviations with which the Author may be familiar but the less expert reader may not). It remains, however, a good account of a well-conceived and successfully carried-out operation.

An article on Soviet Naval Strategy raises interesting points on the subservience of a navy to an army, on the value of Carriers (of which the Soviets have none) and on the capabilities of a navy consisting almost entirely of submarines, even though a percentage of these are nuclear-powered and armed with ballistic missiles.

A discussion on the education of future naval officers brings out the interesting facet that U.S. naval recruiting will be satisfactory as long as the army remains the only branch of the services using the draft—it is evidently preferable to serve three years in the navy as an officer rather than two in the army as a draftee. The following chapter, in dealing with the manning of the fleet, stresses the extensive possibilities which are offered for education in technical fields.

The lagging of doctrines behind technology is the theme of an article on air transport, and this is followed by Admiral Schofield's essay on the British Mercantile Marine and Strategy, which is largely statistical. A later description of the U.S. Merchant Fleet gives a highly interesting account of the working of subsidies, both for operating and building merchant vessels.

Strategy and Oil, a Naval Impression of Brazil, Deep Submergence and Aiding the Navigator are the titles of subsequent essays—the last named contriving, somewhat ingeniously, to omit any reference to Decca or Trinity House, and the final article on Minesweepers—a subject rarely pursued until the need is imminent or overdue—gives a fascinating picture of this Cinderella of naval design.

The Appendices cover recent Naval Chronology, a Commentary on Sea Power (with a perceptive analysis of the passing of the British version), Military Aircraft Command and the Secretary of Defence's Statement before the Senate Appropriations Committee in February 1966. The latter gives, from the U.S. standpoint, a vivid thumbnail sketch of current political activity in every quarter of the globe.

Brilliantly illustrated by photographs, and excellently well produced, this Review will be of great interest to anyone concerned in the study of the wider aspects of naval affiairs.

A. V. Thomas

Modern Materials—Advances in Development and Applications. Vol. 4. Edited by B. W. Gonser and H. H. Hausner. Pp. viii+420. New York and London. Academic Press. Inc. 1964. Price 107s. 6d.

The materials employed in engineering used to be selected almost entirely from those which had been available and in use for a respectable period of years. Nowadays, the pattern is changing, and in some industries designs are actually being developed on the basis of tentative property data which it is hoped will be realised in materials which are under simultaneous development. There is therefore a need for a series of books, such as the one of which this forms a part, which are designed to present up-to-date summaries of the properties of materials, using the term materials in its most general sense.

The book begins with a section on carbon and graphite by Erle A. Shobert, which is followed by a description of the effects of irradiation upon materials and personnel by T. S. Elleman and C. W. Townley. P. G. Forrester of the Glacier Metal Co. contributes a section on materials for plain bearings, and this is followed by a discussion of dry lubricants by R. J. Benzing. The book concludes with a chapter on high-strength steels by A. M. Hall.

The reviewer's copy was marred by bad collation, in that the title page and pages 1 to 4 had been bound between pages 36 and 37.

Inevitably, the style of the book is not uniform throughout, but the chapters are, in general, well-written and supported by references. The difficulties involved in collating data in a field of commercial sensitivity complicated by "more art than science" are particularly evident in the section dealing with plain bearings and caused Mr. Forrester to renew his plea for realistic and established test conditions to be employed and properly reported in order that the efforts of different workers might be effectively correlated.

The confusion which exists in materials terminology is particularly apparent in the last section, dealing with high strength steels. The author has chosen to split his review into "high-strength steels", having a minimum yield strength of 50,000 p.s.i., "extra-high-strength" steels, having a yield strength in the range 80 - 115,000 p.s.i. and "ultra-high-strength" steels which run up to 280,000 p.s.i. yield strength. This last section is particularly disappointing, not just because it is confined to American materials, but because the emphasis is upon production techniques and parts of the chapter read like manufacturers' literature. Few warnings of the hazards to be considered in handling such materials are given, and there is no mention of the precautions required in welding operations nor of the value of fracture toughness concepts in relation to materials of very limited ductility.

The book is therefore a mixed bag of good and indifferent information. It has a place in a reference library, but the information which it contains must be used with due regard to the part of the book from which it comes. Therefore, the value of the book is somewhat questionable, since it can only be used with confidence by readers who already have a sound and comprehensive experience of the field involved.

D. Birchon

Fluid Mechanics. Fourth Edition. By V. L. Streeter. Pp. v+705. Maidenhead; McGraw Hill Publishing Co. Ltd. 1966. Price 80s.

This is the latest revision of a well known text book on Fluid Mechanics, one of the three dozen or so books entitled 'Fluid Mechanics' or 'Fluid Dynamics' which have been issued during the past 12 years.

The book is mainly intended for students of engineering science, but the text covers much more material than is usually given in a first course in fluid mechanics. The book is conveniently divided into two parts, Part I covering 'Fundamentals of Fluid Mechanics' and Part II 'Applications of Fluid Mechanics'.

The early chapters of Part I deal with the properties of fluids, fluid statics, and the underlying framework of concepts, definitions and basic equations for fluid dynamics. A chapter on dimensional analysis and dynamic similitude is inserted before the introduction of the concept of real fluids with viscous effects and resistance. The concept of boundary layer is introduced at this stage and there is a first introduction of experimental data into fluid flow calculations. The concept of compressible flow of both real and frictionless fluids is introduced before the final chapter of Part I which deals with Ideal-fluid flow in both two and three dimensions.

In Part II several of the important fields of application of fluid mechanics are dealt with, starting with 'Fluid Measurement and Control'. A description of various standard techniques for making pressure and velocity measurements are followed by a short section on optical flow measurement using Schlieren, shadowgraph and interferometer techniques. There is a comprehensive section on all types of flow meter ranging from orifice plates and venturi's to rotameters, with some description of their theory and calibration.

The all too short section on fluid control now includes reference to the subject of fluidics, with a clear explanation of fluid amplifiers as well as dealing with the more conventional control systems.

The basic theory of turbomachinery which really deserves a book to itself, is dealt with somewhat briefly, together with a short discussion on cavitation. The last three chapters of the book deal with steady flow in pipes and open channels and finally unsteady flow problems in pipes and open channels. The point is made that the analysis of unsteady flow is much more complex than that of steady flow and a most appropriate method of solution of these problems is by use of a digital computer.

The book ends with five useful Appendices: (a) Force Systems, Moments and Centroids, (b) Partial Derivatives and Total Differentials, (c) Physical Properties of Fluids, (d) Notation, and (e) Computer Programming Aids.

Throughout the book fundamental concepts and conclusions have been developed and illustrated by many examples with simple applications. This latest revision of the book has been brought more up to date by the addition of material on electronic fluid measurements and on pneumatic servo control, the inclusion of fluid amplifiers, a new chapter on unsteady flow and the inclusion of digital computer applications solving some of these problems. In general it is a very well laid out textbook for engineering students trying to gain an understanding of the fundamentals and main engineering applications of fluid mechanics.

F. S. Burt

Control Systems Functions and Programming Approaches. Vols. A & B. By D. N. Chorafas. Pp. xxvi+395 and Pp. xx+276. New York and London. Academic Press, 1966. Prices 128s. and 88s.

In the course of fast moving developments such as computer applications and integrated computer system design, it is salutary that every once in a while someone should stop and look around in all directions to determine what has been happening, what is currently happening, and in what direction 'forward' should lie. My only real criticism of these two volumes is that it should have been Chorafas who stopped, looked, listened and then talked!

A splendid subject, providing vast opportunities for influencing forward thinking, has been covered in words, words, and still more words.

Volume A covers the basics of 'why compute' and the principles of systems analysis. It goes on to deal with the language problems of computers and the requisite translation machinery, leading into Boolean Algebra and programming. Systems control and real time programming loops and systems are considered.

Volume B looks at computer system installations in processing, production, air traffic control and airline seat reservation control, and deals briefly with automation in banking, and road and rail transport control. All very interesting, and—for the systems analyst—extremely good case histories.

But never for the layman nor for the merely interested reader. The approach is tedious in the extreme. All the information one could conceivably want is there, if only one can find it. Chorafas states, in his introduction, that during 1966, in the preparation of the volumes, "multinational research led to meetings in 24 countries on four continents with two Prime Ministers, six ministers of industry and commerce, five ministers of planning, 85 university professors, and a golden horde of leading industrialists." A fine pedigree but he might better have spent the time severely editing whatever material he already had.

Good books, utterly spoiled in their style of presentation. But if you can bear them there is a wealth of information available therein. Volume B (Applications) depends to a large extent on Volume A (Theory), but Volume A can stand on its own.

R. W. Sudweeks

Theory and Research in Lubrication. By M. D. Hersey. Pp. xii+488. New York; John Wiley & Sons, Inc. 1966. Price 140s.

This book serves a double function in that the main text covers the physical and mechanical aspects of lubrication while a very extensive list of references at the end of each chapter covers the subject in a rather broader manner. Lubrication is used in the title without qualification but in the text fluid lubrication, whether it be hydrodynamic, hydrostatic or elasto-hydrodynamic, is the only subject covered in detail.

A glance at the index which does not claim to cover all items mentioned in the text shows those subjects which have not been considered. There is no reference to "Additives", "Oxidation", "Detergents" or "Hypoid Gears" for example and as these are subjects which involve the chemistry of the lubricants and the metal surfaces it is apparent that this side of the subject is not dealt with in detail. The existence of solid lubricants and greases is mentioned but their composition and function is not covered.

Having indicated those areas and aspects which are not dealt with in any detail it should be said that what has been covered has been done well. The historical evolution of the subject is clearly shown and the text and lists of references covers the results of many workers in this field. The papers presented to U.K. Conferences and Symposiums have received proper recognition as has other work published in the British technical literature.

Tribology is the new title for "the science and technology of interacting surfaces in relative motion and of the practices related thereto" and thus includes all aspects of lubrication and wear. The present book is a very welcome addition to the tribologists' library as long as it is realised that the chemistry of the lubricants and surfaces are also important and for much internal combustion engined equipment very important indeed.

R. P. Langston

A Simple Approach to Electronic Computers. By E. H. W. Hersee. Pp. xi+261. New York; Gordon & Breach Science Publishers Inc. 1967. Price $7.50.

There are by now many books dealing in a general and elementary way with electronic computers, and one's reaction to the present volume might well be to decry yet another book on the same subject. This, however, would be a somewhat unfair comment, since this is the second edition of a work which was first published in 1959, when the subject of computers was at a much earlier stage of development, and few general and elementary books were available. Judged in this light it is, however, relevant to ask not only if the work merits a second edition, but also if this new edition has been thoroughly revised and brought up to date. The answer to both these questions is 'Yes'.

The Author's stated aim in this volume is to describe as simply as possible the basic principles of both analogue and digital computers. In fulfilling this aim he has avoided recourse to any mathematics beyond simple arithmetic operations, and the resulting book is lucid and easy to follow. In particular the descriptions of the logical operation of basic circuits, such as those used for addition, subtraction or storage is clearly explained, although the electronic operation of such circuits is not considered.

It is, of course, possible to make some criticisms of any book, and the present volume is no exception, although such criticisms are few. The most important of these concerns the use of technical jargon. Those working with computers have inevitably evolved an extensive jargon which is often confusing to the layman, not because of the concepts involved, but because of its unfamiliarity. Thus we would hope to find, in the present volume, an explanation of terms such as 'NAND GATE', 'ON LINE', 'REAL TIME'. These terms were chosen at random, but none appears in the index. The meaning is, in most cases, implicit in the text, but it would be of considerable interest to be able to associate it with the jargon in general use.

This volume provides a useful introduction to the subject of computers. For a non-specialist volume the price seems rather high, and although many will find it worth reading, few will be encouraged to purchase a copy.

C. H. Gooch

NOTICE TO READERS

The Editor extends to all readers of the JOURNAL a cordial invitation to contribute articles of R.N.S.S., Naval or general scientific and technical interest.

Authors are requested particularly to note that as the JOURNAL is in the Restricted category the printing of material within its pages does not constitute open publication and does not prejudice the subsequent use of the material in the journal of a learned Society or Institution, or in the scientific and technical press.

Manuscript should be typewritten if possible, in double spacing and on one side of the paper only. It should include, in addition to the title, the name of the author together with initials, degrees and Department, Establishment or Ship. Pseudonyms are acceptable only in special circumstances. A convenient length is between 3,000 and 5,000 words, but other lengths are acceptable and no contribution would be debarred on this ground alone.

Illustrations are in most cases a desirable addition. Photographs should be of good quality, glossy, unmounted, and preferably between two and three times the size of the required final picture. Graphs and line drawings should be made on a similar large scale, with bold lines to permit reduction in block making.

Views and opinions expressed in the JOURNAL are not necessarily endorsed either by the R.N.S.S. or by the Editor.

All communications should be addressed to:—

H. L. R. Hinkley, Editor,

Journal of the Royal Naval Scientific Service,
Ministry of Defence,
Station Square House,
St. Mary Cray, Orpington, Kent.

Telephone Orpington 32111 Ext 258

Information Centre
Knowledge Services
[dstl] Porton Down,
Salisbury
Wilts
SP4 0JQ
Tel: 01980-613753
Fax 01980-613970

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#:
Date of Search: 15 February 2007

Record Summary:

Title: Journal of the Royal Naval Scientific Service
Covering dates 1968 Sept
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Note Vol 23 No 5
Held by The National Archives, Kew

This document is now available at the National Archives, Kew, Surrey, United Kingdom.

DTIC has checked the National Archives Catalogue website (http://www.nationalarchives.gov.uk) and found the document is available and releasable to the public.

Access to UK public records is governed by statute, namely the Public Records Act, 1958, and the Public Records Act, 1967.
The document has been released under the 30 year rule.
(The vast majority of records selected for permanent preservation are made available to the public when they are 30 years old. This is commonly referred to as the 30 year rule and was established by the Public Records Act of 1967).

This document may be treated as UNLIMITED.